HIGHWAY RESEARCH REPORT

ULTRASONIC INSPECTION OF BUTT WELDS IN HIGHWAY BRIDGES

FINAL REPORT

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

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16. ABSTRACT

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Problem areas such as operator training, repeat ability of findings, and interpretation and documentation of findings are investigated through both laboratory and in-service structural applications.

This study has shown ultrasonics to be a safe, reliable method for butt weld inspection and has resulted in the use of ultrasonics by the California Division of Highways to supplement and, in some cases, replace radiographic inspection as the primary nondestructive inspection technique.

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DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

October, 1972
Final Report
M&R No. 636210

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

ULTRASONIC INSPECTION OF BUTT WELDS

IN HIGHWAY BRIDGES

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Under the General Direction of

Eric F. Nordlin

Very truly yours,

JOHN L. BEATON
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KEY WORDS: Welding, butt welded joints, testing, nondestructive testing, ultrasonics, ultrasonic testing, quality control, inspection.

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I. INTRODUCTION

For nearly twenty years the California Division of Highways has controlled butt weld quality through nondestructive radiographic inspection. An acceptable radiographic interpretation of a welded connection has been considered sufficient proof of the weld's quality and along with competent visual inspection has completed the inspection record of that joint.

With the arrival of the ultrasonic inspecting technique, it becomes evident that, in a considerable number of instances, ultrasonically detected "flaws" are not apparent on the radiographic record of the joint. Two explanations for discrepancies between the two inspecting techniques are offered:

a. "Tight" small volume flaws which characterize welding error, such as fine cracks, are not normally revealed on "radiographs".

b. Borderline or poor control of radiographic film resolution frequently results in less than optimum contrast and obscured flaw indications.

Weld flaws of the types that cannot be detected radiographically or are the first to be obscured in lower quality radiographs are generally those most easily detected ultrasonically.

Cracks, considered intolerable in structural bridge welding, fall into the above category inasmuch as radiographic testing will not consistently reveal cracks in sections over one inch thick. This has not been a major problem in California with low strength steels like ASTM A36, since the crack tolerance in these steels in warmer climates is generally large enough that failure by section loss would precede brittle fracture in the presence of a crack. Before failure by section loss could occur, the initiating crack would generally have become visible by eye during routine maintenance inspection. However, fracture mechanics principles indicate that the maximum tolerable crack size in welds decreases as the square of the weld metal yield strength. Therefore, with high strength steels such as ASTM A517, critical-size flaws are small enough to be concealed inside many of the heavier welded plate sections now being specified in bridge designs. Since radiographic examination frequently is not sensitive enough to consistently detect cracks of these sizes, the importance of developing a more suitable technique, such as ultrasonics, for the inspection of welded bridge structures is immediately apparent.

With the need established to detect cracks in welds and the evidence from our initial study that ultrasonic inspection is a valuable tool for this purpose, we next studied the repeatability or reliability of this nondestructive test method to detect cracks and the other types of weld flaws such as lack of fusion, lack of penetration, slag and porosity. With this knowledge, an overall engineering decision could be made as to the usefulness of the method and its potential as an all-inclusive acceptance criterion for butt welds.

Minor weld flaws such as small slag stringers or certain conditions of porosity have been considered acceptable using ultrasonics or radiography and left unrepaired in butt weldments. However, we have also seen instances of similar slag and porosity inclusions incorporating cracking, with the cracking undetectable by conventional radiographic inspection. This condition is detected and rejected by the ultrasonic inspection procedures to be discussed later in this report.

It is the author's sincere belief that the conservative nature of existing radiographic standard specifications was an effort on the part of the specification writers to cover the possibility that weld flaws evident on a radiographic film can and often do terminate in cracking not visible on the film. The fact that ultrasonic inspection can detect this suspected cracking only serves to justify the current radiographic specifications and should not be cause for an even more strict interpretation of radiographic film, which would result in repairs being made that should not be necessary.

Ultrasonics has proved to be a safe and portable nondestructive inspection method. It does not require heavy, high voltage power supplies as do magnetic particle and x-ray inspection nor the cumbersome isotope "castles", lead shields, and collimators common to radiographic (isotope) inspection. Workmen in the vicinity of ultrasonic inspection can proceed with their job duties without concern for safety hazards created by ultrasonic inspection, because there are none.

Another major point, which places ultrasonics high on the list of desirable tools for weld inspection is its ability to accurately and precisely locate a defect as well as to determine its size and often its orientation. With this type of information documented, substantial economic savings can be realized through an expeditious weld defect repair procedure.

It is important to remember that ultrasonic inspection also has <u>limitations</u> which prevent it from completely replacing radiographic inspection. The fact that ultrasonic inspection is still a costly, time-consuming operation demands that less expensive inspection methods continued to be used where the special capabilities of ultrasonics are not required. In selecting the most suitable nondestructive testing method, consideration should be given to:

a. types of defects that are of concern

b. weld joint geometry

c. welding procedure used

d. types of defects that are suspected.

The inspection method selected should provide the least expensive method of consistently detecting the types of flaws of most concern. Economic savings can only be realized through ultrasonic inspection if, in fact, this degree of inspection is truly warranted.

The actual economic savings attributable to any inspection operation is difficult to determine because of the preventative function of inspection. The number and severity of structural failures averted by adequate inspection can never be known, making it difficult to justify the expense of the inspection. The major argument for employing ultrasonics as an inspection tool stems from its ability to frequently provide a confidence level above that realized with radiographic and other inspection techniques. Applications of ultrasonics in this study to radiographically accepted welds disclosed defects that, if not detected and repaired, could have initiated failure of the weldments. This was particularly true of high strength steel weldments. It is evident that the use of an inadequate inspection method can lead to a structural failure resulting in repair costs far exceeding either the savings originally anticipated from the use of high strength steels, or the possible additional cost of employing the most suitable inspection method.

The capabilities and limitations of the various nondestructive inspection methods must be recognized and given consideration when selecting the method most suitable for the <u>level</u> of inspection required. Once the best method has been decided upon, it should be used at all phases of the welding quality control and assurance program (i.e., procedure test plates and the weldor qualification test plates as well as in-service weld inspection).

From this study it appears that the time and cost of ultrasonic inspection probably prohibits its application to the amount of butt welding on which radiographic inspection is required under present specification. It is felt, however, that the ultrasonic inspection requirements outlined herein, where needed, will significantly reduce the probability of serious weld flaws existing in the completed structure.

On this basis it appears that radiographic inspection may still be considered sufficient to generally insure the desired structural performance of butt welds in lower strength steels but with some ultrasonic "spot checking". But in high strength steels, where the tolerable flaw size is quite small, ultrasonics should replace radiography as the primary nondestructive inspection method for butt weld acceptance. However, it is probable that there will be a supplemental radiographic "spot check" inspection of some small percentage of ultrasonically accepted welds in an effort to help substantiate the rationale for relying so heavily on ultrasonics.

Included as Appendix A of the report is a "Method of Ultrasonically Inspecting and Evaluating Structural Steel Butt Welds from 1/2-inch to 4-inches Thick."

II. <u>CONCLUSIONS</u>

A. Ultrasonic inspection by the pulse-echo contact method can provide excellent information as to butt weld quality in the 1/2" - 4" thickness range.

B. Ultrasonic inspection can be conducted by experienced <u>technicians</u> (as is the case for radiography) in a systematic and reproducible fashion.

C. The confidence level of ultrasonic inspection is dependent, to a great degree, on the interest in and knowledge of ultrasonics possessed by the inspecting team.

D. Welded joints can yield the same interpretation when ultrasonically inspected by different operators whose instruments are calibrated to the same standard.

E. Because of its three-dimensional capabilities, ultrasonics can pinpoint welding flaws as to <u>depth</u>.

F. Weld cracks, often missed or obscured on radiographic records, are those most easily detected ultrasonically.

G. Due to the shortcomings of existing ultrasonic inspection standards, the need to develop a new specification is in order.

III. RECOMMENDATIONS

A. Ultrasonic inspection should be accepted as a method to insure the quality of butt welded structural steel joints in the 1/2" - 4" thickness range.

B. All butt welds to be ultrasonically inspected must be ground flush and smooth.

C. Only ultrasonic instruments with calibrated gain control in db's (decibels) should be considered for use.

D. The Engineer must pay close attention to the qualifications of the ultrasonic operators. The Engineer must also insure that the specifications are being adhered to and that the operator's instrument, standard calibration blocks, and transducers meet these specifications.

E. All personnel inspecting the fabrication and splicing of primary structural steel bridge members by welding, both in the shop and the field, should be schooled in the basic theory and practice of ultrasonics, covering both the operation of the ultrasonic instrument and the interpretation of the ultrasonic specification.

F. Welding Procedure and Weldor Qualification Test Plates should be subject to ultrasonic inspection where this nondestructive test method is required on the butt welds for which the test plates serve as prototypes.

IV. TECHNICAL DISCUSSION

A. Sources of Information

In the five years of research by the authors into ultrasonic weld inspection, there was determined a definite need for ultrasonic inspection in conjunction with and in comparison with established radiographic inspection requirements.

As a part of this research ultrasonics was employed in the following areas:

1. welding procedure test plates submitted to the laboratory
2. weldor qualification test plates submitted to the laboratory
3. specially prepared plates with known weld flaws
4. flange and web butt welds in ASTM A-36, A-441, A-588, A-514 and A-517 steel bridge construction
5. cross frame to flange welds in some A-517 steel bridge construction
6. miscellaneous applications on an experimental basis.

All new information gained through this research has come from one of the above areas and has been combined with state-of-the-art knowledge to comprise this report.

B. Ultrasonic Inspection Personnel

The most common reason for ultrasonics being labeled an inadequate inspection tool in the past, lies in the quality of the inspecting personnel. Lack of interest, dexterity, or intelligence of the operator has been a major obstacle in trying to develop, evaluate, and apply ultrasonics as a routine inspection technique. The writers of this report have spent considerable time in learning the state-of-the-art of ultrasonics. This study began with numerous courses on basic and advanced ultrasonic theory, which later progressed to simple and complex laboratory demonstrations, and, at present, includes the full evaluation of butt welded shop and field bridge girder splices. These experiences show that a good welding and technical background as well as a keen interest in ultrasonics in general are absolute musts for an ultrasonic inspector. The operator of the ultrasonic equipment is of paramount importance because the information he detects and ultimately interprets on the ultrasonic screen determines whether the weld is rejectable or acceptable as outlined by the specification. He must have the ability to (1) manipulate the ultrasonic transducer while watching the screen, (2) efficiently maximize all weld flaw indications so that proper evaluation can be made, (3) know when a particular situation gives interpretation difficulties and what corrective action should be taken, (4) and perform the inspection with a degree of consistency condusive to repeatability of findings. These are all operator influenced situations that must be recognized if correct and accurate flaw interpretation are to be made.

It is the opinion of the researchers that an ultrasonic inspection team should generally consist of two test-qualified technicians. Requalification of an ultrasonic operator should be required if he has been inactive for a period of three (3) months. An operator's qualifications should be subject to revocation by the party contracting the ultrasonic inspection (hereafter referred to as "the Responsible Party(s)") whenever his performance is inadequate.

C. Ultrasonic Equipment

1. General

The ultrasonic equipment used in this work was that required for ultrasonic inspection by the pulse-echo contact method. Although all of the different equipment commercially available was not employed in this study, it is felt that the equipment that was used was a good representation of current ultrasonic technology.

The equipment requirements and calibration procedures recommended as the result of this research are outlined in Appendix A of this report.

2. Ultrasonic Test Instruments

In the course of the research the following models of ultrasonic test instruments were operated. These instruments were made available at no cost by both manufacturers' and private inspection agencies. They are:

a. Branson Sonoray 301, 601

b. Krautkramer Model USK 4, USK 5, USIP 10W

c. Magnaflux PS 702

d. Sperry US, UCD, UVP, UM 721, Immerscope 725, UM 735

All those which incorporated the calibrated gain control feature proved capable of yielding equivalent results when used in their intended manner. It was concluded that the calibrated gain control is a necessary feature where accurate flaw <u>size</u> evaluation is required.

After the operation of the more popular manufactured units, four Branson Sonoray Model 301 test instruments were purchased for use in the major portions of this study because of the following desirable features they exhibited:

a. This instrument represented several years of experience in the relatively new field of portable ultrasonic equipment.

b. Calibrated attenuation <u>switches</u> rather than knobs allowed faster, less confusing flaw evaluation.

c. An adequate CRT screen eliminated the need for eye-irritating screen magnification windows or reflecting mirrors.

3. <u>Transducers</u>

a. Longitudinal wave - The longitudinal wave transducer requirements are listed in Appendix A.

b. Shear wave - This work included the use of both "angle wedge" and "potted" (fixed angle) transducers. Both types proved acceptable. The angle wedge type with its interchangeable lucite "angle shoes" is desirable because the less expensive lucite shoe takes all the wear and the service life of the more expensive <u>transducer</u> element is greatly increased. Also, because the lucite angle shoes are interchangeable, the capability of many different inspection angles can be realized with an investment in only one expensive transducer element and several less expensive angle shoes. The "potted" type transducers are smaller and less cumbersome, but more expensive. For each different scanning angle desired, a complete and separate transducer must be used. (See Appendix A for the shear wave transducers requirements.)

4. <u>Miscellaneous Equipment</u>

Other equipment necessary or helpful in ultrasonic inspection is listed in Appendix A, Section II. B. 3. b. (5).

5. <u>Calibration</u>

In order that discontinuities may be accurately evaluated and pinpointed as to location, and to insure the repeatability of inspection findings, the ultrasonic equipment must be properly calibrated with an invariant standard. Calibrations may be classified as a. "regular", b. "occasional", or c. "periodic".

a. "Regular" calibrations must be performed at the inspection site and checked at various times (see Appendix A, Section II. B. 5) during the welding inspection operation. The distance (horizontal sweep) and sensitivity calibrations are in this category and require small, portable calibration standards which must be taken into the field and used in a quick and simple fashion.

For straight beam inspection the "Type D.C." Distance Calibration Block (Appendix B, Figure 2) has been adopted by the authors as the field standard, mainly because it is also adequate for angle beam distance calibration.

For angle beam sensitivity calibration the "Type S.C." Sensitivity Calibration Block (Appendix B - Figure 3) proved most desirable as a field standard. Desirable features of the "Type S.C." block, include:

(1) an artificial flaw at the same sound path distance for all three angles (45°, 60° and 70°) enabling a more absolute calibration and evaluation

(2) an artificial flaw which provides a uniform reflecting surface across the greatest dimension of the rectangular beam cross-section, thus providing an averaging effect on discrepancies attributable to odd "beam profiles"

The "Type S.C." block also provides a separate but equivalent reflector for each angle (45°, 60° and 70°), with a sound path one inch (1") long so as to provide a -3db standard "reflector" in each case.

The Ultrasonic Reference Block (see Appendix B, Figure 1), a modified form of the I.I.W. Reference Block is, however, the recognized standard for both distance and sensitivity calibration. Its standard sensitivity reflector (see Appendix C, Section II. D. 3) is defined as a 0 db flaw in the 70° scan, only, and forms the basis for all commonly used "flaw size - db" relationships. Features of the I.I.W. Reference Block which make it less desirable for sensitivity calibration are:

(1) its single standard reflector for all scanning angles does not account for differences in sound path distance (attenuation) at different scanning angles.

(2) its standard reflector when scanned at 45° is close enough to the transducer to fall in an unstable portion of the sound beam, thus yielding inconsistent reflections.

(3) its large size and weight are not conducive to field use.

b. "Occasional" calibrations are those performed or checked at extended intervals (every 40 hours) on angle beam transducers, and include the evaluation of the following characteristics (see Appendix A, Section II. B. 3. b. (3):

(1) angle of sound in steel

(2) sound emission index point

(3) internal reflection level

(4) resolution capabilities

(5) flatness of contracting surface

c. "Periodic" calibration checks of the ultrasonic equipment are performed at one year intervals. This check is not intended to be done by the ultrasonic technician, but is to be made and certified by the instrument manufacturer or one of his authorized service representatives. Functions to be specifically checked for accuracy are the calibrated controls, horizontal, and vertical linearity, plus the overall performance of the equipment.

6. Equipment Recommendations

Based on experience from this study, it is recommended that the following features be considered in the future design and manufacture of portable ultrasonic equipment to be used in shop and field weld inspection:

a. Ultrasonic Test Instrument

(1) moisture and dust proof calibrated gain control knobs or switches

(2) rugged shock resistance construction

(3) shock resistant transporting and/or shipping case

(4) modular construction

(5) lightweight (less than 15 pounds)

(6) longer battery life (minimum of 8 hours)

(7) bright and sharp cathode ray tube trace

b. Transducers

(1) minimized ringing from initial "bang"

(2) standardized "beam profiles"

c. Accessories

1. a battery charger indicator that tells if the batteries are, in fact, receiving a charge

2. a battery charger regulator to prevent battery damage from overcharging

3. multiviscosity couplant, usable over a wide range of temperatures and scanning surface orientations

D. Inspection Procedure

The recommended inspection procedure for butt welded joints entails two operations, namely: (1) a straight beam ("longitudinal wave") scan of the "base metal" on either side of the weld, (2) an angle beam ("shear wave") scan of the weld metal for both longitudinal and transverse defects.

The procedure for each of these operations is discussed separately below.

1. Ultrasonic inspection for base metal soundness.

Using a straight beam search unit, the base metal on either side of the weld should be scanned for "laminar flaws" and other inclusions. Although these flaws may not pose a direct threat to the strength of the welded joint, they may prohibit angle beam weld inspection and/or yield spurious flaw indications. Therefore, all base metal through which angle beam weld inspection will be conducted must be inspected. If laminations prohibit proper ultrasonic inspection, two courses of action are available to the Responsible Party:

a. Remove the base metal containing the lamination and replace it with sound material, thus creating an addition butt weld subject to the inspection requirements of the original weld.

b. Allow the laminated area to remain and evaluate the weld using incomplete ultrasonic data or an alternate nondestructive inspection method and confidence level.

2. Ultrasonic inspection of weld metal.

Ultrasonic inspection of weld metal is accomplished using an angle beam (shear wave) transducer. "Angle" refers to the angle from normal of the refracted sound beam in the test piece, and is selected on the basis of the test piece thickness, mindful that:

a. the entire volume of the weld must be penetrated by both slant and "V" paths of reasonable length

b. both longitudinal and shear waves do not act simultaneously to produce strong reflections.

Inspection of weld metal should include a scan for "longitudinal discontinuities" (hereafter called "longitudinal scan") and a scan for "transverse discontinuities" (hereafter called "transverse scan"). Scanning (see Appendix "D") should be conducted from both sides or both directions and on the same face where mechanically possible. By requiring a scan by both "slant" and "V" paths, one is better able to evaluate the weld and the following difficult situations:

a. "stacked" flaws (see Section IV. I. 5. of this report)

b. flaws near the scanning surface

c. flaws in planes aligned parallel to the axis of the slant path.

When a flaw is detected with a properly calibrated instrument, it must be evaluated by means of the calibrated gain controls. Basically, this is accomplished by scanning at a sensitivity level greater than the reference sensitivity and noting the gain adjustment required to reduce the flaw signal to the "horizontal reference line" on the Cathode Ray Tube (CRT). As sound waves travel through steel, their strength (sensitivity) is diminished or attenuated at an average rate of 1 db per inch of sound travel. This means that the magnitude of the reflected "signal" is not an absolute measure of flaw size. The amount of "attenuation" due to beam travel must be calculated and considered in the evaluation of the flaw. Because distance to the flaw (one-half the total length of beam travel) is a more common and useful value than the length of beam travel, the correction required is expressed as a function of the former by specifying a correction of +2 dbs per inch beyond the first inch of path distance to the flaw. (One inch need not be corrected for because calibration was based on a one inch flaw distance.)

The "scanning sensitivity" of +27 db (see Appendix B - Table I) was selected so as to allow the detection and evaluation of the smallest recordable flaw if it exists at the far end of the greatest anticipated sound path for a given thickness plate. The critical case is the 70° "V" path in 1-1/2" thick material.

From the "Ultrasonic Beam Penetration Diagram" (Appendix B, Figure 6), it is seen that the "V" path length for this case is approximately nine (9) inches. Keeping in mind that beam sensitivity diminishes with length of travel and the requirement of detecting a +11 db reflector (the applicable "Recordable Defect" level from Table I), it follows that the initial sensitivity level must be great enough to offset the expected diminishment (+16 db) and still detect and evaluate the +11 db reflector. Thus the +27 db scanning sensitivity.

Since scanning is conducted at a sensitivity of +27 db or 30 dbs more sensitive than the reference sensitivity (-3 db from Appendix C, Sec. II.D.6), it is easiest to adjust the signal height to the horizontal reference line with 30 dbs of attenuation adjusted into the system. It is then simply a matter of increasing the sensitivity by 30 dbs to attain the scanning sensitivity of 27 db. On some instruments the finest adjustment possible with the calibrated gain control is 2 db. A more accurate flaw valuation can be made if the "dynamic range" of the instrument is such that one vertical division in the 50% height area of the CRT screen represents a 1 db change in sensitivity. In this case, the signal is brought as close to the 50% screen height as possible with the calibrated gain control and the calibrated screen divisions enable a finer reading for the final evaluation. With this procedure followed, accuracies of ±1 db have been realized.

When a "reflector" is encountered and maximized during scanning, its magnitude (rating) is determined by the following relationship:

<u>Flaw Magnitude (db) equals</u>

Scanning Sensitivity (+27 db)	-	Sensitivity correction of 2 db for every inch, after the first, of distance <u>to</u> the flaw.	-	The change in gain (db necessary to reduce the flaw signal to the horizontal reference line from the scanning sensitivity.

A table has been constructed to assist the ultrasonic inspecting team in determining whether the detected flaw is of a recordable magnitude (see Appendix B - Table II). It takes into consideration the attenuation correction for length of sound path. If the amount of gain necessary to reduce the flaw signal to the horizontal reference level is greater than the appropriate value in Table II, the flaw should be recorded.

Because signal amplitude (flaw size indication) is not directly proportional to the amount of gain acting in the system, the actual size relationship between two discontinuities is not the same as the relationship between their respective db-ratings. (e.g., a discontinuity with a rating of +2 dbs is not twice as large as one with a rating of +4 dbs.) This fact has been considered in establishing the acceptance - rejection criteria in terms of db ratings. Table III of Appendix B shows the ratio of signal heights for various db ratings and enables the comparison of ideally reflected signals (flaws).

The location of the flaw is determined from the angle and sound path distance in the maximized position using simple trigonometry. The "Ultrasonic Beam Penetration Diagram" (Appendix B -Figure 6) has been constructed to expedite this process. Using the sound path distance to the flaw (indicated on the horizontal axis of the CRT screen) and knowing the angle of the sound beam in the metal, it is a simple matter to obtain the flaw depth and the horizontal distance from the sound source to the flaw. When a "bounce" scanning pattern is used, a discrepancy has been observed to exist between this calculated horizontal distance and the actual horizontal distance to the flaw. For the 45° shear wave path this discrepancy is negligible, but for the 60° and 70° paths the anomaly becomes great enough to warrant application of the following corrections to the horizontal distance to the flaw:

for 60° path . . . . - 1/8" per bounce
for 70° path . . . . - 1/4" per bounce

Flaw length is the actual distance between the "extremities" of a flaw. The determination of the extremities of a flaw is based on the fact that a 6 db drop in a flaw's signal height represents loss of half of the flaw's maximized reflection. It can readily be seen that when the center vertical axis of the beam is on a flaw's extremity, only half of the beam will be intercepted by the flaw and will be portrayed as a 6 db drop in signal height on the CRT screen (Appendix B - Table III).

E. Documentation (Recording)

The documentation procedure requires that a written record of the results of each scan be completed by the ultrasonic inspection team at the time of inspection. A separate "Ultrasonic Test Record" must be completed for the longitudinal and the transverse scans of each butt weld (Appendix B, Figures 12 and 13 respectively). At the end of each day's inspection an "Ultrasonic Summary Sheet" (Appendix B - Figure 15), should be completed to serve as a tabulation of that day's inspection results.

As a result of this project, flaw severity levels were determined to establish the type and magnitude of ultrasonically detected flaws that should be recorded (Appendix B - Table I). Table I, which outlines the guidelines for flaw evaluation, is empirically based on past applications of ultrasonics and other forms of nondestructive testing. Because the initial use of ultrasonics in this research project concentrated heavily on inspection for major defects (cracks) not consistantly detectable by radiography, the researchers became most familiar with the ultrasonic representation of this type of flaw. From the findings in this area and through comparison with radiographs and other nondestructive tests, it was possible to extrapolate and assign degrees of severity to the ultrasonic representations of other types of flaws.

F. Interpretation and Evaluation of Findings

It should be emphasized that the Ultrasonic Record of a joint documents all of the flaws of recordable magnitude that are present in the weld. This information must then be interpreted to determine which "discontinuities" to accept and reject. Thus, the record, after interpretation may show both "flaws" (acceptable discontinuities) and "defects" (rejectable discontinuities). The documentation of flaws exhibiting slightly less than "Rejectable" severities, i.e., flaws of only a "Recordable" magnitude, is required for various reasons:

1. Quite often a weld defect will be clearly rejectable by the scan from one side, while the scan from the opposite side discloses a flaw of less than rejectable magnitude. Documenting both the rejectable and the non-rejectable flaw indication information, (e.g., size, length, depth and location) as is recommended, provides supporting data for defining the characteristics of the defects.

2. Recording ultrasonically acceptable weld flaws of a borderline type allows future monitoring of weld flaws either after adjacent weld repairs have been made or later in the active life of the welded joint.

3. It has been found that the fastest way to determine whether or not an adequate calibration of ultrasonic equipment has been maintained by the ultrasonic inspection personnel is by taking their ultrasonic test record and comparing it with one that your forces have conducted on the same weldment. A check of their ultrasonic scanning sensitivity and accuracy is immediately apparent.

4. It is not felt that an adequate analysis of a weldment can be made by the ultrasonic personnel on a defect-by-defect evaluation. It is contended that a weldment should be evaluated as a whole which requires all pertinent weld flaws to be documented,

including the obviously rejectable ones. In this way the operators can concentrate on an accurate ultrasonic scan. Upon completion of the inspection, the ultrasonic summary sheet can be prepared at which time a careful evaluation of the ultrasonic test record can be conducted in a more condusive atmosphere.

5. The db accuracy of most ultrasonic inspection equipment and the fine dividing line between acceptance and rejection criteria suggest that "borderline" flaws should be on record.

6. This information can be used to analyze problem areas (weldor, welding procedure, etc.) as they develope and to enable corrective action to be initiated before the problem becomes more severe.

Flaw severity is based on magnitude in db's and the flaw's dimension transverse to the beam direction and is determined in accordance with one of the following two criteria:

1. If the portion of a flaw's area able to be irradiated by the beam is sufficient to provide a maximized reflection meeting the "Excessive Defect" requirements in Appendix B - Table I, the flaw is rejectable on the basis of its reflected signal alone. These are frequently the gross slag inclusion, lack of penetration, lack of fusion and the crack type defects.

2. If the portion of a flaw's area able to be irradiated by the beam is <u>not</u> sufficient to provide a maximized reflection in the "Excessive Defect" range, the flaw may still be rejected if of sufficient length, as in the case of "Large Defects" and "Moderate Defects" (see Appendix A, Section II, E). These are usually the lack of fusion, slag and group porosity type defects.

Table I of Appendix B sets forth criteria for the interpretation of ultrasonic inspection findings, but the interpreter's experience and judgment should also enter into the decision as to which weld flaws will require repair. The value of an ultrasonic inspector with an extensive weld inspection background is evident.

The ultrasonic test method outlined in Appendix A is an attempt on the part of the authors to overcome weaknesses in existing ultrasonic weld inspection specifications. Two other specifications currently controlling the ultrasonic inspection of butt welds in highway bridges are the American Welding Society's "Specifications for Welded Highway and Railway Bridges" (AWS D2.0-69), and the Federal Highway Administration's

"Specification for the Ultrasonic Testing of Butt Welds in Highway and Railway Bridges" (May 1, 1968). Each of these incorporates certain points which is felt to be unrealistic or not in keeping with sound principles of quality inspection.

The American Welding Society specification uses the I.I.W. Ultrasonic Reference Block Standard 1/16 inch diameter hole as its sensitivity standard for each of the three transducer angles. In each case the artificial flaw is said to represent a 0 db flaw, when in actuality this is not the case. When the transducer angle is changed, the screen indication amplitude varies due to the following:

a. Different attenuation effects arise from the change in sound path length (angle).

b. Beam geometry and sensitivity vary at different points within the "near" portion of the sound path, creating changes in sensitivity as the sound path length (angle) changes.

A 0 db reflector is, by definition, the I.I.W. reflector when scanned using a 70° transducer only. When the same reflector is scanned with the 60° and 45° transducer, the sound path is reduced, resulting in less attenuation and the reflector being irradiated by a more intense point along the beam. Consequently, the gain must be reduced to bring the screen indication to the same height as the 70° indication. The flaw evaluations produced by 45° and 60° scans calibrated thusly are less severe than they would be based on a valid calibration. An effort is made to compensate for this difference in the scanning angle within a given thickness range. As a result, no single absolute rejection level exists for each thickness range. It is felt that three different acceptance-rejection levels for each material thickness range creates unnecessary confusion in documentation and interpretation for the ultrasonic operators.

It is readily seen that if a calibration block would provide a standard reflector at the same sound path distance for all three angles, the confusing situation mentioned above could be eliminated (assuming that transducers of the same frequency have generally the same beam characteristics at points equidistant from the transducer). The "Type S. C." block provides this feature.

The Federal Highway Administration ultrasonic specification (May 1, 1968) likewise uses the I.I.W. standard flaw as its sensitivity standard for all angles, and invites the same confusion as the A.W.S. specification. In addition to this, it bases defect length limits on radiographic rejection lengths from the A.W.S. specification. This proves unrealistic because ultrasonics is able to more closely measure the actual length of a flaw rather than the shorter "projected length" often seen by radiographic methods. This results in ultrasonic rejection of radiographically acceptable flaws.

In addition, both specifications conclude that the documentation record show only rejectable defects, those defects which must be removed. The authors believe this procedure is inadequate for the reasons previously discussed.

G. Marking of the Defective Welds for Repair

Once it has been established that specific welds will require repair, a sketch of each defective weld should be made (see Appendix B - Figure 14) by the ultrasonic operators. It should consist of plan and elevation views clearly showing the location and size of all rejectable defects contained in that weld. The sketch should be submitted to the Responsible Party to enable him to supervise the marking of the defects on the structure.

In marking defective welds, defect length should be shown by a line on the surface directly over the defect, running the entire length of the defect. The depth below the surface should be marked out of the weld area with a suitable line and arrow.

H. Repair and Final Ultrasonic Inspection

After all repairs resulting from ultrasonic rejection have been completed, the Responsible Party should request a second ultrasonic inspection of the weld. The inspection should conform to the requirements previously set forth and should cover the repaired area including two (2) inches on all sides of the repair.

When the Record shows only acceptable flaws remaining in a weldment, it is deemed ultrasonically acceptable. A series of repair operations and subsequent ultrasonic inspections may be required to attain this level.

I. Difficult Inspection Situations

1. Thin plate

It has been observed that ultrasonic inspection is, at this time, unfeasible for plate (welds) less than 1/2" thick. A 1/2" wide beam tends to "flood" the material with "sound", making detection of small, critical size cracks and other defects of concern for this thickness very difficult.

2. Plate thickness transition areas

Plate thickness transition areas, whether in the form of an unground weld or a specified change in design thickness, create serious scanning problems that the ultrasonic operators must be aware of.

When an angle beam strikes the transition surface, it is highly likely that reflection or "mode conversion" or both will occur. With mode conversion occurring, there is a doubling of the wave velocity for that portion which was converted, resulting in misleading screen indications.

By requiring welds to be ground flush with the flange surface and limiting the evaluation if any portion of the beam is suspected of striking the transition surface when scanning from the thick side of the transition, the possibility of problems is minimized.

3. Unground Welds

Experience with ultrasonic inspection of butt welds indicates that the most accurate interpretation of a welded joint can be realized if the weld area has been ground flush with the adjacent base metal surface to a maximum roughness of 250 micro inches (RMS). These grinding requirements are based on the following observations:

a. The unground weld crown usually produces a back signal where normally there would be none. This may tend to obscure flaws that actually exist in the unground weld's surface and/or create a condition that requires an interpretation on the part of the operator. The latter situation should be avoided whereever possible.

b. Scanning for transverse flaws cannot be conducted from directly over the weld zone, when the weld is in the unground condition. Also a straight beam scan of the base metal under the weld crown is impossible.

c. With the weld in the unground condition, the entire weld zone cannot be scanned with both the slant and "V" paths as is desirable.

4. Side by side discontinuities

Ultrasonic inspection on occasion indicates the existance of two separate flaws side by side with only one being severe enough to require repair. The repair operation, however, discloses that the defect is actually one continuous discontinuity. The repair operation in this case should follow the flaw and include the flaw portion not rejected ultrasonically.

5. Stacked discontinuities

Flaws sometimes occur one behind or below the other along the sound path, with the flaw nearest the transducer acting to shield or "hide" the further one. By requiring slant and "V" path scans from both sides of the weld, this problem can be minimized.

6. Misleading flaw terminations

Oftentimes, a 6 db change in signal height will be caused by a change in a flaw's reflectability (i.e., flaw size and/or orientation) rather than by the fact that the flaw's extremity is being scanned. The requirement for scanning with both slant and V-paths from both sides of the weld should minimize this problem.

J. Ultrasonic Inspection by Outside Agencies

With the reliance on ultrasonics as a primary inspection tool, it is hoped that an increased dependence can be placed on the work of outside testing and inspection agencies. In the past, many of these agencies have argued that the small amount of ultrasonic butt weld inspection available did not warrant the cost of training their personnel to these or similar standards. Also, because many outside inspection agencies are involved in a wide range of ultrasonic applications, with butt welds constituting only a very minor portion, it is difficult to obtain the necessary degree of concern and conscientiousness required for proper ultrasonic inspection of butt welds. The competitive nature of the industry frequently seems to encourage getting the job done as quickly as possible, often at the sacrifice of quality.

It should be pointed out that ultrasonic operators participating in this study have found that in order to conduct a meaningful ultrasonic inspection according to the standards outlined herein (performing the necessary cleaning, weld labeling, documentation, cleanup, etc.), a minimum of 1 1/2 hours per foot of weld length should be allotted.

On the other hand it is questionable that ultrasonic inspection by private agencies should be permitted on critical butt welds in steel bridges until the "in house" structural steel inspectors become schooled in the use of ultrasonics and are capable of exercising some degree of moniter control over its use.

Until the volume of bridge butt welding requiring ultrasonic inspection increases, and until other states increase their reliance on ultrasonics as a reliable nondestructive inspection technique, the authors recommend that private inspection agencies continue to be called upon only in times of manpower shortages. In these cases they will provide an assistant for an established inspector in order to fulfill the requirement for a two man inspection team. In this situation the outside agency's equipment is used where possible and the duties of scanning and recording will be handled alternately by the two inspectors.

K. New Application of Ultrasonics Resulting from This Research

In the course of this study, the authors found it necessary to develop a technique for ultrasonically inspecting double groove full penetration web-to-flange welds. The method found to be successful employed longitudinal wave inspection to determine if any unwelded "land" area remained between web and flange. It is anticipated that there will be other applications for this technique in the future. The basic inspection criteria is as follows:

Ultrasonic equipment shall be calibrated using a 5/64" flat bottom hole @ 2-inches of steel travel, with a midscale (50% screen height) indication from this hole serving as the standard 0 db reference level. Discontinuities with indications more than -10 db greater than the reference level will be deemed unsatisfactory regardless of length. All scanning is to be conducted on the flange face opposite the weld. The transducer movement during scanning is to include a smooth back and forth movement which will encompass the weld fusion zone plus one transducer diameter on each side. The re-establishment of the flange thickness signal during the time the transducer is passing the central or root area of the weldment is a sign of lack of root penetration. The evaluation of such discontinuities follow the above mentioned criteria. (The reader should be cautioned that this inspection procedure will reveal incomplete root penetration and it is not intended to be used for a total weld quality evaluation.)

L. Glossary of Terms

active area - that area of the transducer face that is energized (usually the diameter of the crystal portion of the transducer face).

attenuation - the act of losing sound energy by absorption or dispersion.

base metal - the metal comprising the members to be joined by a weldment.

beam profile - the distribution of acoustic pressure (beam intensity) within the beam cross-section.

bounce - the reflecting of a sound beam from any free surface of the test piece.

decibel (db) - unit for measuring the relative magnitude of sound energy; used in ultrasonics as a measure of flaw size.

defect - a discontinuity of rejectable severity.

defect magnitude or rating - the severity of a defect as measured in db.

discontinuity - any imperfection or void in a solid material.

dynamic range - the change of sensitivity necessary in the ultrasonic instrument to reduce the signal height from the top to the bottom of the CRT graticule.

flaw - a discontinuity of less than rejectable severity.

flaw magnitude or rating - the severity of a flaw as measured in db.

flush - flat, so as to form a continuous plane with an adjacent planar surface and allow continuous intimate contact with the entire transducer face at any point in the "scanning zone.

high strength steel - steel having a yield stress above 80 KSI.

horizontal reference line - mid-screen horizontal line used to compare returning ultrasonic signals.

laminar flaw - an internal metal separation creating layers generally parallel to the surface.

longitudinal discontinuity - a weld discontinuity whose major axis lies parallel to the weld centerline.

longitudinal scan - scan in which the forward motion of the transducer is in a direction normal to the centerline of the weld.

longitudinal wave - sound wave in which the wave particles oscillate in the direction of wave travel.

maximized discontinuity - a discontinuity irradiated to produce its greatest detectable reflection.

mode conversion - the conversion of longitudinal wave to shear wave or shear wave to longitudinal wave that sometimes occurs during beam reflection or refraction.

Lack of fusion - a defect characterized by a void created when weld metal fails to fuse.

lack of penetration - a defect characterized by a void created when weld metal fails to penetrate the root of the weldment.

point of restraint - any point where the yield strength may exceed the critical stress intensity because of section geometry and/or residual triaxial stresses induced during fabrication by welding, cutting or forming operations.

porosity - a defect characterized by small spherical voids as a result of gas entrapment in the weld.

radiograph - exposed radiographic film depicting a welded joint.

reflector - anything producing an indication on the CRT Screen in ultrasonic inspection.

scanning zone - that area on the surface of the plate which is used in both slant and "V" path shear wave weld inspection.

screen height - the distance between the lowest and highest horizontal grid lines on the CRT screen.

sensitivity - the degree of response of the ultrasonic test machine to a detected reflector.

signal - CRT Screen indication representing a reflector.

slant path - path of an angle beam from the transducer to the first bounce.

shear wave - sound wave in which the wave particles oscillate perpendicular to the direction of wave travel.

test piece - material being inspected.

transverse discontinuity - referring to a weld discontinuity whose major axis is perpendicular to the weld centerline.

transverse scan - scan in which the forward motion of the transducer is in a direction parallel to the centerline of the weld.

ultrasonic inspection - using ultrasonic equipment (within its capabilities) to determine information about material thickness or quality.

"V" path - the path of an angle beam between the first and second bounce.

weld quality - the physical condition of a weldment (i.e., the presence or absence of defects) deposited in accordance with an accepted welding procedure proved to be capable of developing the required mechanical properties (ultimate strength, yield strength, elongation, etc.) of the joint.

APPENDIX "A"

"Method of Ultrasonically Inspecting and Evaluating Structural Steel Butt Welds From 1/2 inch to 4 inches Thick"

Materials and Research Department

State of California

Department of Public Works

Division of Highways

APPENDIX "A"

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APPENDIX "A"

I. SCOPE

This method specifies the equipment, procedure, and acceptance - rejection criteria to be used in the ultrasonic inspection of full penetration butt welds for structural steel bridges.

II. GENERAL REQUIREMENTS

A. Extent of Ultrasonic Inspection

1. Structural Welds

When contract special provisions or plans require ultrasonic inspection and evaluation, such inspection shall be performed by the Engineer or his agents on portions of the total weld lengths as follows:

a. 100% of each full penetration butt weld between 1/2" and 4" thick which joins a primary tension or compression girder flange

b. 25% of each full penetration transverse web butt weld 1/2" or over in thickness regulated as follows:

(1) the section(s) of weld to comprise the 25% will be selected by the Engineer

(2) in the event that the section(s) of weld inspected is found defective, the Engineer may elect to have 25% of the uninspected weld inspected ultrasonically and if this is found defective, the remainder of the weld

c. 10% of each full penetration longitudinal web butt weld 1/2" or over in thickness regulated as follows:

(1) the section(s) of weld to comprise the 10% will be selected by the Engineer

(2) in the event that the section(s) of weld inspected is found defective, the Engineer may elect to have 10% of the uninspected weld inspected ultrasonically and if this is found defective, the remainder of the weld

2. Test Plates

When contract special provisions or plans require ultrasonic inspection of welded joints, the welding procedure and welder qualification test plates, which serve as prototypes of those joints, shall be inspected for the full weld length and accepted ultrasonically, in accordance with this test method, prior to being sectioned for destructive testing.

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B. Prerequisites for Ultrasonic Inspection

1. Notification of the completion of welding requiring ultrasonic inspection.

a. When ultrasonic inspection and evaluation is specified for the butt welds in a structure, the contractor shall notify the Engineer in writing not less than 10 days before the completion of the first weld requiring such inspection.

b. The written notification of this need for ultrasonic inspection shall identify the requesting contractor, fabricator, and the contract and structure for which the request is being submitted. It shall list the places and the approximate dates planned for this inspection.

2. Scheduling Inspection

The Engineer will schedule ultrasonic inspection and evaluation at the request of the Contractor subject to the following conditions:

a. Requesting Ultrasonic Inspection.

(1) If the contractor only provides time and space for ultrasonic inspection intermittantly, each time he requires such inspection he shall submit his request to the Engineer not less than 24 hours in advance. This request shall identify the welds that are ready to be inspected so that the Engineer can verify the accessibility and preparation of these welds before he schedules the requested ultrasonic inspection.

(2) If the contractor schedules fabrication and erection at such a rate that he can support continuous ultrasonic inspection and evaluation, and if he provides time and space for this inspection to proceed in an uninterrupted manner, he shall maintain and provide the Engineer or the Engineer's agent with a 6 hour notice of the identity and location of each weld that is ready for inspection. This will allow time for the Engineer or his agent to verify the preparations and accessibility of the welds and to optimize his ultrasonic inspection schedule.

b. Ultrasonic inspection and evaluation will not be scheduled until welds have been prepared by the fabricator as follows:

(1) Web-to-flange fillet welds within 6 inches of either side of the butt weld to be inspected shall be withheld until after ultrasonic inspection has been completed and the butt weld has been accepted.

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(2) All shear studs, stiffeners, brackets bolt holes, and other projections or obstructions within the ultrasonic "scanning zone", extending 13 inches on either side of the weld centerline, shall be removed or left off until after ultrasonic inspection has been completed and the butt weld has been accepted.

(3) Backup plates and run-off tabs (if any) shall be removed.

(4) Weld shall be ground flush and smooth with a maximum roughness not to exceed 250 microinches rms.

(5) All loose mill scale, rust, dirt, grease, oil, grime, weld spatter, etc., shall be removed from the scanning zone and the flange or plate surfaces within the zone shall be finished with a maximum roughness not to exceed 250 microinches rms.

(6) Tight layers of paint need not be removed unless their thickness exceeds 10 mils.

(7) The joint to be inspected shall be properly identified for record purposes.

c. Prior to the initiation of ultrasonic inspection the joint to be inspected shall have been visually inspected by the Engineer for surface defects and conformance to joint preparation requirements.

d. Ultrasonic inspection and evaluation shall not be scheduled for welds that are not safely accessible.

e. Ultrasonic inspection and evaluation will not be scheduled outside of daylight hours.

f. Ultrasonic inspection and evaluation will not be scheduled for less than 4 hours irregardless of weld length. (Experience has shown that ultrasonic inspection according to this standard normally requires 1 1/2 hours per foot of weld length.)

3. Conditions for Performance

a. Personnel

Unless otherwise approved by the Engineer, ultrasonic inspection and evaluation will be performed whenever possible by a team of not less than two ultrasonic inspectors, each of whom shall possess the following minimum qualifications:

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(1) a graduation from high school

(2) a certificate from a training agency approved by the Engineer verifying that he has received not less than 160 hours of training in the ultrasonic inspection techniques outlined in either the U. S. Government Manual entitled "Ultrasonic Testing Inspection for Butt Welds in Highway and Railway Bridges" or the American Welding Society Specifications D1.0 or D2.0 Appendix C

(3) not less than 6 months of experience in the ultrasonic inspection techniques outlined in either the U.S. Government Manual entitled "Ultrasonic Testing Inspection for Butt Welds in Highway and Railway Bridges" or the American Welding Society Specifications D1.0 or D2.0 Appendix C

(4) approval by the Materials and Research Department based on a demonstrated level of proficiency and understanding in performing the ultrasonic calibrating, scanning, documenting, and evaluating techniques prescribed in this Test Method

(5) twenty-twenty vision or vision correctable to 20-20, verified by proof of an eye examination performed within the three years prior to the day the work is to be performed.

Requalification under paragraph (4) above will be mandatory when a lapse of three months of inactivity has passed in the use of the authorized ultrasonic inspection and evaluation techniques on California Division of Highways contracts.

Qualification under paragraph (4) above may be revoked at the Engineer's discretion anytime he finds an ultrasonic inspector's performance inadequate.

b. Equipment

Ultrasonic inspection and evaluation will be performed using not less than a minimum inventory of equipment and accessories as follows:

(1) one or more ultrasonic test instruments each of which shall meet the following requirements:

(a) The ultrasonic test instrument shall be of the pulse-echo type. It shall generate, receive, and present on a cathode-ray tube screen (hereafter "CRT screen"), pulses in the frequency range from one to six megahertz (MHz). The presentation on the CRT screen shall be the "video" type and characterized by a clean, sharp trace.

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(b) The horizontal linearity of the test instrument shall not deviate more than 2 percent over the linear range which shall include 90 percent of the sweep length presented on the CRT screen for the longest sound path used. The horizontal linearity shall have been certified by the instrument manufacturer or his authorized service representative not longer than 1 year prior to the day of use.

(c) The <u>vertical linearity</u> of the test instrument shall not deviate more than 5 percent over the linear range which shall include the CRT screen above 10 percent and below 90 percent of the screen height. The vertical linearity shall have been certified by the instrument manufacturer or his authorized representative not longer than 1 year prior to the day of use.

(d) The test instrument shall be equipped with an internal electronic circuit or an external constant voltage transformer to stabilize the operating voltage. In either case, stabilization must be achieved within plus or minus 2 volts over an input voltage range of 90 to 130 volts.

(e) Test instruments utilizing battery power shall include internal stabilization resulting in no greater variation than plus or minus 1 db following warm-up during battery operating life. There shall be an alarm or meter incorporated in battery powered instruments to signal a drop in voltage because of battery exhaustion prior to instrument shut-off.

(f) The test instrument shall have a calibrated gain control (attenuator) adjustable in discrete 1 or 2 decibel steps over a range of at least 60 decibels. The accuracy of the gain control settings shall be within plus or minus one decibel and this accuracy shall be certified by the instrument manufacturer not longer than 1 year prior to the day of use.

(g) The test instrument shall be capable of adjustment to provide a CRT display with a "dynamic range" of 10 $\pm$ 2 dbs wherein a 6 db increase in signal shall cause the amplitude of the displayed trace to increase from 20 $\pm$ 5 to 80 $\pm$ 5 percent of the screen height.

(2) one or more straight beam (longitudinal wave) search units suitable for thickness and soundness determinations of the steel to be inspected in accordance with the requirements of Section II. C. 2. of this test method, and meeting the following requirements:

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(a) Each straight beam search unit shall have an "active diameter" not less than 1/2 inch nor more than 1 inch.

(b) The fundamental transducer resonant frequency of each straight beam search unit shall be between 2.25 and 5 megahertz (mHz) inclusive.

(c) Each straight beam search unit, when coupled to the test instrument to be used in inspection, shall be capable of resolving the three sound path distances as described in Appendix C, Section I. C. of this test method.

(d) Each straight beam search unit shall be sufficiently free of internal reflections induced by transducer ringing and capable of detecting laminar flaws as close to the contact face as 1/4 of the thickness of the material to be examined when adjusted to the sensitivity level described in Section II. B. 5.b. 3. (b) of this test method.

(e) Each straight beam search unit shall be clearly marked with the following:

1.1 identifying serial number

1.2 manufacturer's name

1.3 fundamental transducer resonant frequency

(3) one or more angle beam (shear wave) search units suitable for scanning the welded steel joint thicknesses to be inspected in accordance with Section II. C. 3. of this test method, and meeting the following requirements:

(a) Each angle beam search unit shall consist of a transducer and an angle wedge. The unit may be comprised of the two separate elements or it may be an integral unit ("potted" transducer).

(b) The transducer crystal of each angle beam search unit shall be 1 inch in length and 1/2 inch in width.

(c) The fundamental transducer resonant frequency of each angle beam search unit shall be between 2 and 2.5 megahertz (MHz) inclusive.

(d) Each angle beam search unit shall have a nominal angle of refraction of 45, 60, or 70 degrees in steel.

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(e) Each angle beam search unit shall produce a sound beam that is within plus or minus 2 degrees of its nominal angle of refraction in steel when tested in accordance with Appendix C, Section 11. B. of this test method.

(f) Each angle beam search unit, when coupled to the test instrument to be used in inspection and tested at 20 dbs above the sensitivity standardized in accordance with Appendix C, Section II. D. of this test method, shall not have internal reflections above the horizontal reference line on the CRT that are to the right of the sound entry point by more than that distance on the screen representing sound travel through 1/2 inch of steel.

(g) Each angle beam search unit, when coupled to the test instrument to be used in inspection, shall be capable of resolving the three holes in the resolution test block shown in Appendix B - Figure 4.

(h) Each angle beam search unit shall be marked to clearly indicate the following:

1.1 the manufacturer

1.2 the dimensions of the active face of the transducer

1.3 the fundamental resonant frequency of the transducer

1.4 the nominal angle of refraction in steel (indicated by a number representing the angle followed by letter "s" to represent steel)

1.5 a identifying serial number

1.6 a mark denoting the sound emission index point located as described in Appendix C, Section II. A. of this test method.

(i) With the contacting surface of the transducer or wedge held to the light with a straight edge laid in contact with the surface, there shall exist no indication of curvature in either the longitudinal or transverse direction.

(j) Shear wave transducers that are incased in a holder ("potted" transducer) shall not vary in sensitivity more than $\pm$ 1 db due to handling and manipulating pressures.

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(k) After every 40 hours of use, the following items of a shear wave transducer shall be checked to conform with the requirements of this test method:

1.1 angle in steel

1.2 sound emission index point

1.3 internal reflection level

1.4 resolution

1.5 contact surface flatness

(4) one Ultrasonic Reference Block or an I.I.W. Block conforming to the dimensions specified in Appendix B, Figure 1, and one Distance Calibration Block and Sensitivity Calibration Block conforming to the dimensions specified in Appendix B, Figure 2 and 3 respectively.

(5) accessories as follows:

(a) a light shield for the screen of the test instrument for work in bright light

(b) a stainless steel wire brush

(c) a tape measure and ruler

(d) a metal file ("flat bastard")

(e) a paint marker (permanent type)

(f) a one inch brush for couplant

(g) a small couplant container filled with glycerine couplant

(6) It is considered the responsibility of the qualified ultrasonic operator(s) to be cognizant of the ultrasonic equipment as to its accuracy and conformance with the standards presented herein and to take corrective action independently if it is noted to fall below standard at any time between the 1 year periodic equipment calibration checks.

If the Engineer at any time, finds the equipment to be below the standards specified herein, sufficient cause exists for disqualification of the ultrasonic operator(s).

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c. Environmental Requirements:

(1) Ultrasonic inspection and evaluation will not be conducted in the presence of rain or blowing sand nor in the presence of winds exceeding 10 mph except under shelter approved by the Engineer.

(2) Ultrasonic inspection and evaluation will not be conducted outside of daylight hours.

(3) Ultrasonic inspection and evaluation will not be conducted at locations which the Engineer does not consider safe.

(4) Ultrasonic inspection and evaluation will not be performed when the temperature of the steel to be inspected is below 50 or above 120 degrees Fahrenheit.

(5) Any device producing a magnetic field which could cause signal distortion on the CRT screen shall be removed from the inspection area.

4. Preinspection Procedure

Prior to beginning any ultrasonic inspection, the inspecting team shall:

a. flush the complete scanning zone clean with water

b. inspect the surface condition of the scanning zone to assure conformance with Section II. B. 2. b. (4) of this test method

c. verify the joint identification markings and note them on the test record

d. construct a continuous reference centerline on the weld surface depicting the approximate centerline of the weld

e. mark weld length reference numbers in appropriate positions outside the scanning zone (i.e., 24-inch length of weld is marked 0" at one end and 24" at the other)

f. mark direction letters (either N - S or E - W) in their appropriate position outside the scanning zone

g. all markings shall be made using permanent type marking paint and shall agree with those noted on the test record

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5. <u>Calibration of the Equipment</u>

a. Calibration for sensitivity and horizontal sweep for the particular material to be inspected shall be performed or checked at the following times:

(1) at intervals not exceeding thirty (30) minutes when in use

(2) prior to and upon completion of each plate or weldment

(3) when there is a change of operators

(4) when there is a change of transducers or transducer cables

(5) when there is a change of power source

(6) when there is a change of scanning method

(7) at any time the operator suspects it is necessary

(8) upon request of the Engineer.

Calibration should be attempted only after the instrument has been given sufficient time to warm up. If the sensitivity has varied more than five percent (5%) since the last sensitivity check, rescanning shall be required of the full amount of weld or plate that was scanned since the last sensitivity check.

b. Calibration for straight beam (longitudinal wave) testing shall be accomplished as follows:

(1) Horizontal sweep shall be adjusted for distance calibration according to Appendix C, Section I. A. to represent the equivalent of at least one plate thickness on the CRT screen.

(2) Material thickness measurement sensitivity shall be adjusted at a location free of extraneous indications ("grass") so that the first back reflection from the far side of the plate will be 90 to 100 percent of full screen height. For this purpose, the reject (clipping) control shall be turned off.

(3) Base material soundness test sensitivity shall be attained by the following procedure:

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(a) The reference sensitivity shall be adjusted at a location free of extraneous indications ("grass") so that the first back reflection from the far side of the plate will be 50 to 60 percent of full screen height. For this purpose the reject (clipping) control shall be turned off.

(b) The scanning sensitivity for base material soundness shall be 16 dbs more sensitive than the reference sensitivity.

(c) To maintain a calibrated scan the calibrated gain control shall be the only adjustment permitted during testing.

c. Calibration for angle beam (shear wave) testing shall be accomplished as follows:

(1) The transducer angle shall be selected in accordance with Appendix B, Table I on the basis of material thickness.

(2) The horizontal sweep shall be adjusted according to Appendix C, Section II. C. so as to represent the actual length of the sound path, with full screen representing 0-5", 0-10", or a combination of 0-10" and 5"-15". Full screen calibration for length of sound travel shall be capable of representing a full weld inspection with both the slant and "V" paths.

(3) The dynamic range of the instrument shall be such that, when properly calibrated to a 10 db dynamic range, a change of 6 dbs will reduce the signal height of any reflector from 80% to 20% of the CRT screen height.

(4) Calibration for sensitivity shall be in accordance with Appendix C, Section II. D.

(5) When calibrated for angle beam testing, the instrument shall meet the following requirements:

(a) The signal height from the standard sensitivity reflector when maximized shall not exceed 50% or be less than 45% of total screen height.

(b) The instrument, shall have the capability of increasing the sensitivity 27 dbs to the scanning sensitivity (see Appendix B, Table I).

(6) To maintain a calibrated scan the calibrated gain control is the only adjustment permitted during scanning.

APPENDIX "A"

(7) Equipment calibration checks shall be performed when the responsible Engineer feels there is a need to do so. Such instrument calibration check shall be performed in the presence of the requesting Engineer.

(a) In the event that the instrument and transducer are not calibrated to comply with the requirements of this specification:

(1.1) All future ultrasonic inspection work utilizing this equipment is prohibited until such time it is demonstrated to the satisfaction of the Engineer that the problem has been corrected and the instrument is calibrated.

(1.2) Depending on the severity of the instrument calibration deficiency, the responsible Engineer will determine to what extent previous inspection done with the deficient equipment will require reinspection, if any.

(b) In the event the equipment is found to be correctly calibrated, additional time will be allowed to compensate for the inspection time lost during the calibration check.

C. Inspection Procedure

1. General

Ultrasonic inspection of a butt welded joint shall include two operations:

a. a straight beam (longitudinal wave) scan to determine the soundness of the base metal on either side of the weld

b. an angle beam (shear wave) scan of the weld metal itself to detect both longitudinal and transverse defects

2. Ultrasonic inspection for base metal soundness.

All ultrasonic inspection for base metal soundness shall be conducted with the approved equipment accurately calibrated.

a. Procedure

(1) Scanning shall be conducted so as to reveal all laminar defects contained in all base metal through which subsequent angle beam inspection of weld metal will be conducted.

APPENDIX "A"

(2) Base metal soundness inspection shall not be attempted on material less than 0.200 inches thick.

(3) Adequate couplant (glycerine) shall be used to insure continuity between transducer and test piece.

b. Documentation and Evaluation

(1) If the base material exhibits no internal reflectors but does exhibit a clear and continuous back reflection, check the "No Laminations" box on the longitudinal scan record sheet and proceed to Part 3, "Ultrasonic Inspection of Weld Metal Using the Angle Beam Search Unit".

(2) If the base material exhibits a positive internal reflector (a positive internal reflector is defined as any reflector observed on the CRT screen that is of fifty (50) percent screen height or more when the sensitivity is brought back to within +6 dbs of the reference sensitivity from the scanning sensitivity of +16 dbs), document the area on the back of the Ultrasonic Test Record showing the extent of the condition within the inspection zone. (See Section II. C. 2. b. (4)).

(a) The extremities of all laminar reflectors are determined by scanning along the surface of the plate to a point where the reflector drops to 50% screen height at a sensitivity level of +12 dbs from the standard reference sensitivity.

(b) If the reflector is regained within 1/2 the transducer face dimension in the direction of scanning the condition shall be considered to be continuous throughout the interim distance.

(c) Notify the Engineer if the condition exceeds 2 inches in any 24 inches of weld length. Continue inspection with care in those areas of laminations if the condition is deemed acceptable by the Engineer.

(3) In base material with many positive internal reflectors or base material which exhibits no positive internal reflectors and no positive back reflection (no positive back reflection is defined as a condition where the back reflection drops to 50 percent screen height or below at the scanning sensitivity of + 16 db's), document the area on the record sheet showing the extent of the condition within the inspection zone.

APPENDIX "A"

(a) The extremities of the condition where loss of back reflection is observed shall be determined by scanning along the surface of the plate to a point where the back surface reflection is regained to 50% screen height at a sensitivity level of + 10 db's from the standard reference sensitivity.

(b) If the condition is regained within 1/2 the transducer face dimension in the direction of scanning the condition shall be considered to be continuous throughout the interim distance.

The Engineer shall be notified and further weld inspection may require an alternate scanning procedure or nondestructive inspection method suitable to the Engineer.

(4) Laminar defects in base metal shall be documented on the back of the Ultrasonic Test Record for the longitudinal wave scan as follows:

(a) Construct a coordinate system on the record sheet representing the scanning surface in the area of the defect and reference the origin to the nearest edge of plate and to the weld centerline. The lines of this coordinate system shall be parallel to the edge of the plate and the weld centerline.

(b) Construct the same coordinate system on the scanning surface.

(c) Determine the boundary of the laminar condition with the transducer, noting its intersection with the coordinates on the record sheet.

(d) Connect these intersection points with a line so as to form a bounded area representing the extent of the defective area.

3. <u>Ultrasonic inspection of weld metal using the angle beam search unit</u>.

All ultrasonic inspection for weld quality shall be conducted with the approved equipment accurately calibrated. Prior to angle beam inspection of the weld metal, all base metal through which the angle beam inspection must pass shall have been inspected in accordance with Section II. C. 2. of this test method.

APPENDIX "A"

a. Scanning Procedure

(1) Weld metal inspection shall include a scan for longitudinal defects (hereafter called "longitudinal scan") and a scan for transverse defects (hereafter called "transverse scan").

(2) Adequate couplant (glycerine) shall be used to insure continuity between transducer and test piece.

(3) Scanning patterns shall conform to those described in Appendix D.

(4) Longitudinal and transverse scans shall be conducted from both sides and directions respectively, and from the same face where mechanically possible.

(5) A complete scan will reveal all longitudinal or transverse discontinuities of recordable severity in the length of the weld.

(6) All discontinuities shall be evaluated at their point of maximum reflection.

(7) Scanning for longitudinal and transverse discontinuities shall be conducted at a level of + 27 db.

(8) In flange thickness transitions, "V" path inspection from the thick side of the transition will not be accepted unless it can be proven that the sound beam is reflecting off the surface of the plate clear of the transition area.

b. Documentation and Evaluation

(1) The evaluation of a discontinuity shall include the nominal correction for sound attenuation in steel, which is 2 db's for every inch of sound path distance to the flaw after the first inch.

(2) All discontinuities, regardless of length, shall be recorded if their evaluated severity is of a magnitude equal to or greater than that shown in Appendix B, Table I under "Record Discontinuity".

(3) All recordable discontinuities shall be noted on the Ultrasonic Test Record sheets Appendix B, Figure 7. A separate Ultrasonic Test Record shall be constructed for the longitudinal and transverse scan (see Appendix B, Figures 12 and 13) and shall include the following:

APPENDIX "A"

(a) the location of the maximized discontinuity relative to the edge of the plate (end of the weld) or other reference point

(b) the location of the "extremities" of the discontinuity relative to the edge of the plate (longitudinal flaws) or centerline of the weld (transverse flaws). "Extremity" shall be defined as that point at which the rating becomes 6 dbs less severe than the maximized rating.

(c) the length of a discontinuity as measured from the center of the transducer at one extremity to the center of the transducer at the other extremity

(d) the maximized discontinuity rating in decibels (dbs) with plus or minus sign as applicable

(e) the path in which the discontinuity was evaluated, i.e., slant path, "V" path, "N" path, and "W" path (slant path is understood when no indication of path is noted)

(f) the discontinuity depth from the scanning surface

(g) the discontinuity position relative to the reference centerline - the following corrections for bounce shall be applied to the horizontal distance between flaw and transducer:

with 45° transducer: no correction

with 60° transducer: -1/8" per bounce

with 70° transducer: -1/4" per bounce

(4) If a flaw is of a rejectable magnitude as seen from any scanning direction, the flaw shall be documented from the other direction, regardless of its magnitude as seen from that direction. If the flaw cannot be seen from the opposite scanning direction, note on the record sheet in the corresponding location, "Not Seen".

(5) The inspection results for each day shall be tabulated on the "Ultrasonic Inspection Summary Sheet", Appendix B, Figures 8 and 15.

(6) An ultrasonic documentation package shall be made up for each day's inspection activity and shall include a Summary Sheet backed by the appropriate Ultrasonic Test Record Sheets.

APPENDIX "A"

The order of the record sheets for any particular weldment scan shall be as follows:

(a) base material soundness scan (when applicable)

(b) longitudinal scan test record

(c) transverse scan test record.

D. Clean-Up

Upon completion of any ultrasonic inspection, the total area exhibiting couplant shall be flushed thoroughly with water and wiped dry.

E. Interpretation

1. All ultrasonically detected flaws shall be grouped according to severity as follows:

a. Insignificant discontinuity - degree of severity is too small to justify concern. No record is made.

b. Recordable discontinuity - any discontinuity, regardless of length, whose maximized severity equals or exceeds the appropriate "Recordable" level from Appendix B, Table I.

c. Moderate discontinuity - any discontinuity, two inches (2") or more in length, whose maximized evaluated severity equals or exceeds the appropriate "Moderate" level from Appendix B, Table I.

d. Large discontinuity - any discontinuity 3/4" or more in length whose maximized evaluated severity equals or exceeds the appropriate "Large" level from Appendix B, Table I.

e. Excessive discontinuity - any discontinuity, regardless of length whose maximized evaluated severity equals or exceeds the appropriate "Excessive" level from Appendix B, Table I.

2. Any flaw (discontinuity) meeting the sensitivity and length criteria of the "Moderate", "Large" or "Excessive" classifications shall be considered rejectable.

3. A discontinuity regardless of length with a maximized evaluated rating in the Moderate or Large Defect classification

APPENDIX "A"

shall be rejected when the distance between such discontinuity and a rejected defect does not exceed 2 times the length of the rejected defect.

4. A discontinuity regardless of length with a maximized evaluated rating in the Moderate or Large Defect classification shall be rejected if the discontinuity begins closer than 2 times its length from the edge of a flange or "point of restraint".

5. If a discontinuity of rejectable magnitude is detected and is not able to be verified by a scan from the opposite direction, the decision as to the disposition of the flaw should be the Engineer's based on the type of defect and degree of severity suspected.

6. In addition to the criteria mentioned above, the experience and judgment of the interpretor shall enter into the evaluation and disposition of a discontinuity.

F. <u>Notification of Interpretation to the Engineer</u>

1. Weld inspection documentation which includes the ultrasonic record sheets along with the appropriate ultrasonic summary sheet(s) shall be released to the Engineer by the end of the normal work day.

2. The ultrasonic record sheets and the applicable summary sheet(s) shall be reviewed and discussed between the ultrasonic operators and the Engineer, after a mutual agreement is reached, the Engineer shall sign and date the applicable summary sheets.

3. Any changes to the ultrasonic summary sheet by the Engineer during the time of discussion shall be so changed with the Engineer's initials accompanying each change.

G. <u>Marking of Defective Welds for Repair</u>

1. After establishing which welds will require repair, the ultrasonic inspecting team shall submit a sketch(s) (Appendix B, Figures 11 and 14) of the defective weld(s) to the Engineer. This sketch shall include plan and elevation views of the weld clearly showing the location and size of all rejectable defects contained in that weld, and shall enable the Engineer to supervise the marking of those defects on the weld.

2. Defective welds shall be clearly marked in the presence of the Engineer, on the surface and side he specifies repairs shall be made from.

APPENDIX "A"

3. Markings shall clearly indicate the length and depth of the defect.

   a. Defect length shall be noted by a line on the surface directly over the defect, running the entire length of the defect.

   b. Depth from the noting surface shall be marked (out of the weld area) with a suitable line or arrow referencing the applicable defect.

4. After all defects are clearly marked and with the approval of the Engineer, the ultrasonic operators shall be dismissed.

H. <u>Final Ultrasonic Inspection</u>

1. All repaired plate or weldments resulting from ultrasonic rejection shall be reinspected with ultrasonics.

   a. All reinspection utilizing ultrasonics shall conform to the requirements stated above.

   b. All ultrasonic reinspection shall include the repaired area plus a minimum of two inches on all sides of the repaired area.

2. When the plate or weldment ultrasonic record sheet shows only acceptable discontinuities remaining, the plate or weldment is deemed ultrasonically acceptable.

[illegible]

APPENDIX "B"

TABLES AND ILLUSTRATIONS

APPENDIX "B" - TABLES AND ILLUSTRATIONS

THICKNESS	$\frac{1}{2}$"–1"	>1"–$1\frac{1}{2}$"	>$1\frac{1}{2}$"–2"	>2"–3"	>3"–4"
SEARCH UNIT ANGLE	70°s	70°s	60°s	45°s	45°s
SCREEN HORIZ. CALIB.	0–5" 0–10"	0–10"	0–10"	0–10"	0–10" 5–15"
SCANNING SENSITIVITY	+27 db	+27 db	+27 db	+27 db	+27 db
RECORD DISCONTINUITY	+13 db	+11 db	+9 db	+6 db	+4 db
MODERATE DEFECT	+12 db	+10 db	+8 db	+5 db	+3 db
	+11 db	+9 db	+7 db	+4 db	+2 db
	+10 db	+8 db	+6 db	+3 db	+1 db
LARGE DEFECT	+9 db	+7 db	+5 db	+2 db	0 db
	+8 db	+6 db	+4 db	+1 db	−1 db
	+7 db	+5 db	+3 db	0 db	−2 db
EXCESSIVE DEFECT	+6 db	+4 db	+2 db	−1 db	−3 db

Table I

MINIMUM REJECTION LEVELS (DECIBELS)

ANGLE	THICKNESS (IN.)	RECORD SENSITIVITY (db)	LENGTH ALONG SOUND PATH (IN.)																						
			1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5	5 1/2	6	6 1/2	7	7 1/2	8	8 1/2	9	9 1/2	10	10 1/2	11	11 1/2
70°	1/2	13	14	14	13	12	11	10																	
	3/4		14	14	13	12	11	10	9	8	7														
	1		14	14	13	12	11	10	9	8	7	6	5	4											
70°	1 1/4	11	16	16	15	14	13	12	11	10	9	8	7	6	5	4	3								
	1 1/2		16	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0					
60°	1 3/4	9	18	18	17	16	15	14	13	12	11	10	9	8	7	6									
	2		18	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4							
45°	2 1/4	6	21	21	20	19	18	17	16	15	14	13	12	11	10										
	2 1/2		21	21	20	19	18	17	16	15	14	13	12	11	10	9									
	2 3/4		21	21	20	19	18	17	16	15	14	13	12	11	10	9	8								
	3		21	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6						
45°	3 1/4	4	23	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7					
	3 1/2		23	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5			
	3 1/4		23	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4		
	4		23	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2

TABLE II

ATTENUATION REQUIREMENTS FOR RECORDABLE FLAWS
(SCANNING SENSITIVITY = + 27db)

TABLE III DB RATIO CHART

DB	RATIO	DB	RATIO
0	1 to 1	32	40 to 1
2	1.25 to 1	34	50 to 1
4	1.6 to 1	36	63 to 1
6	2 to 1	38	80 to 1
8	2.5 to 1	40	100 to 1
10	3.2 to 1	42	125 to 1
12	4 to 1	44	160 to 1
14	5 to 1	46	200 to 1
16	6.3 to 1	48	250 to 1
18	8 to 1	50	316 to 1
20	10 to 1	52	400 to 1
22	12.5 to 1	54	500 to 1
24	16 to 1	56	630 to 1
26	20 to 1	58	800 to 1
28	25 to 1	60	1000 to 1
30	32 to 1	62	1250 to 1

NOTE

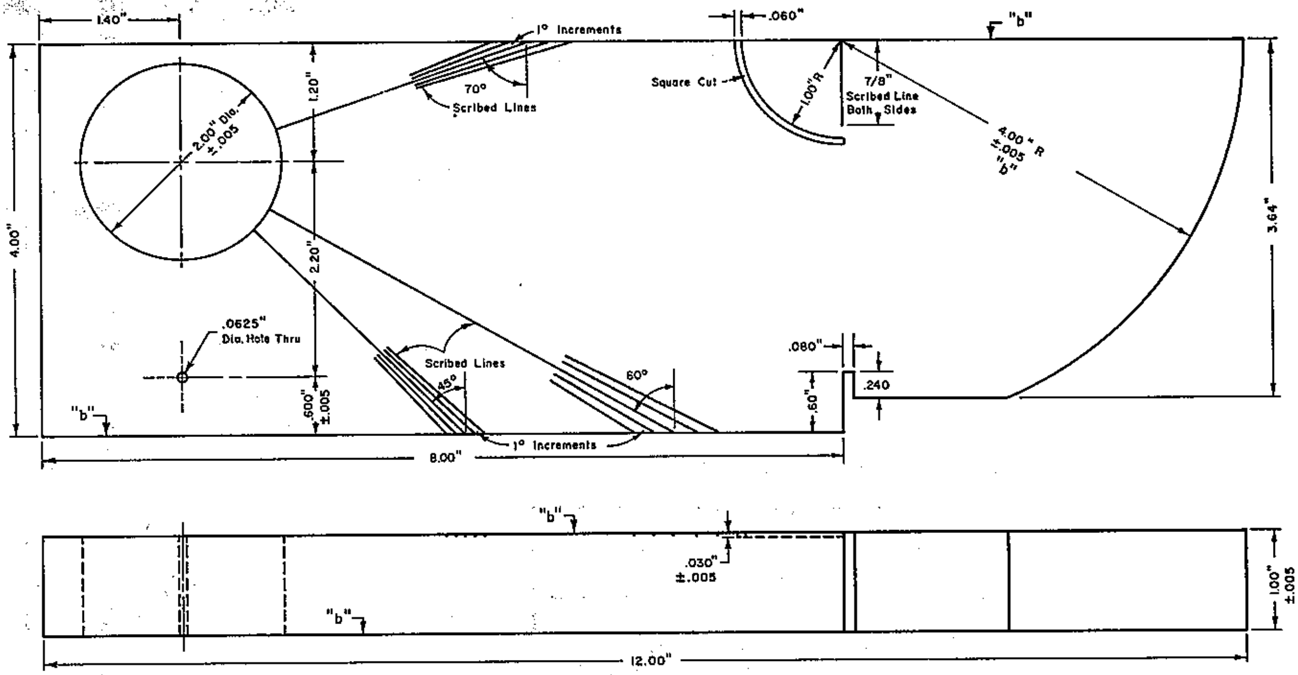


Figure 1
ULTRASONIC REFERENCE BLOCK

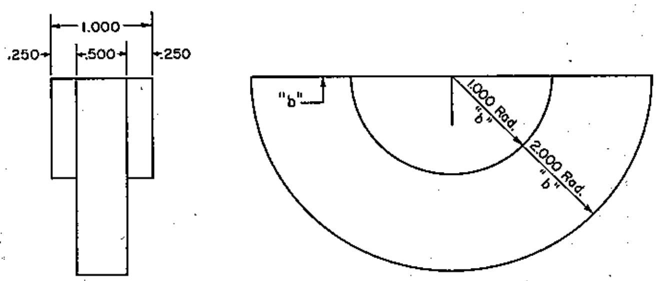


Figure 2
DISTANCE CALIBRATION BLOCK

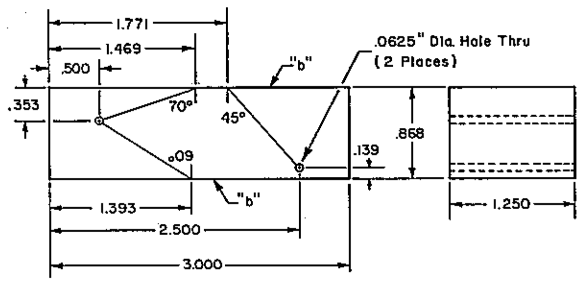


Figure 3
SENSITIVITY CALIBRATION BLOCK

Material: Steel ASTM A-36 or equivalent.

Notes: International Institute of Welding (IIW) approved reference blocks with slightly different dimensions or distance calibration slot features are permissible.

Figure 1 is the California Division of Highways approved Ultrasonic Reference Block.

Sound entry lines are to be identified by indentations in the surface.

Minimum surface roughness:

"b" = 125 microinches, rms.

others = 250 microinches, rms.

Figure 4, the Resolution Test Block is 3" x 1½" x 6" with 1/16" diameter holes 1" deep drilled at 90° to the surface.

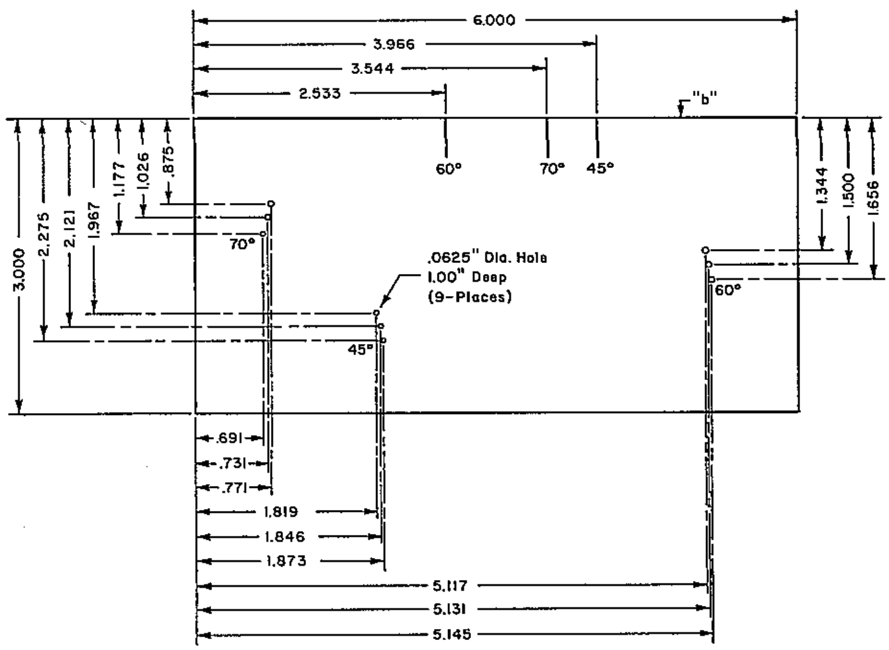


Figure 4
RESOLUTION TEST BLOCK

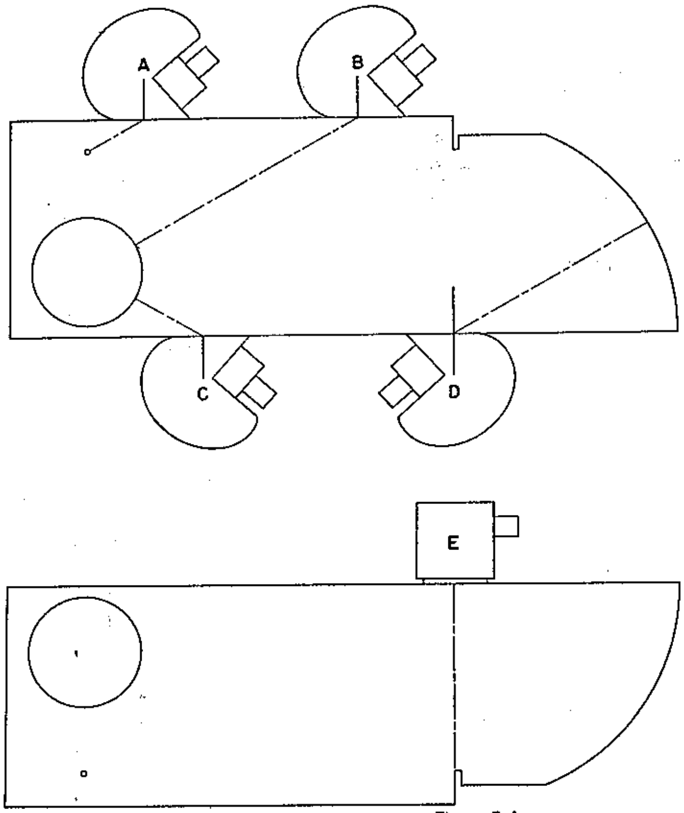


Figure 5-1
ULTRASONIC REFERENCE BLOCK

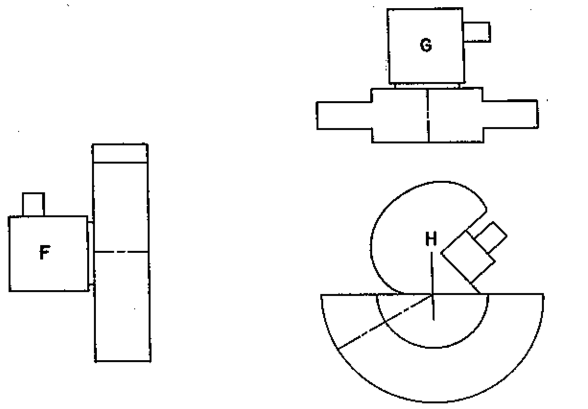


Figure 5-2
DISTANCE CALIBRATION BLOCK

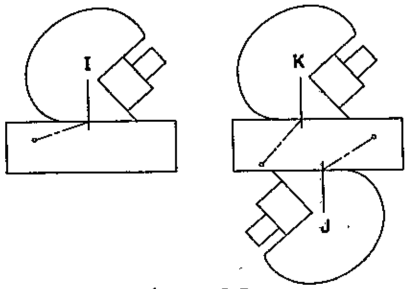


Figure 5-3
SENSITIVITY CALIBRATION BLOCK

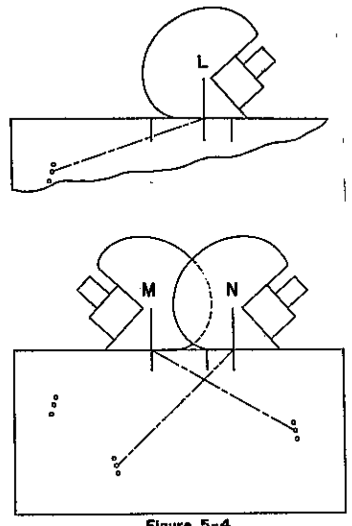


Figure 5-4
RESOLUTION BLOCK

Figure 5

CALIBRATION AND TESTING TRANSDUCER POSITIONS

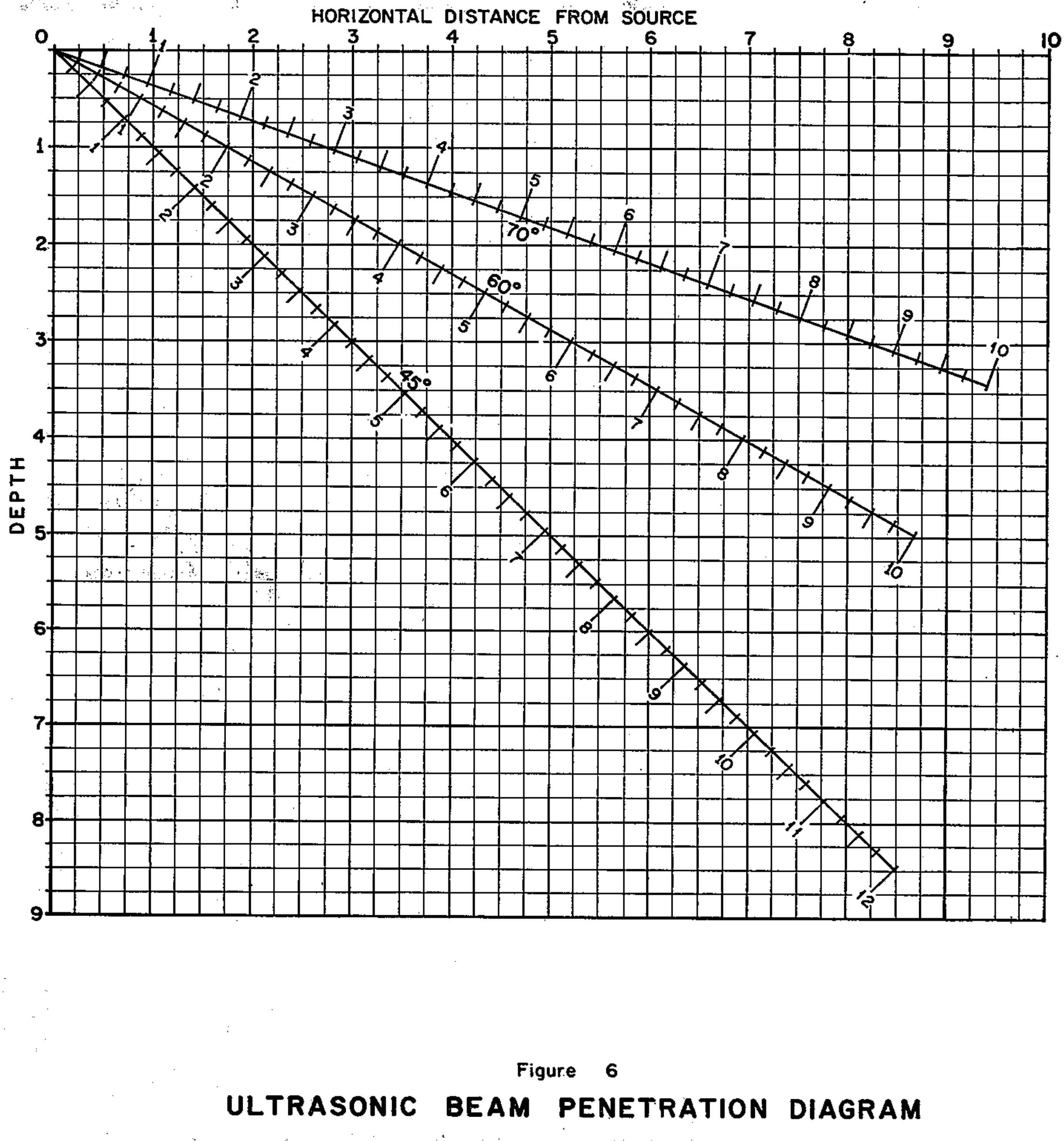


Figure 6

ULTRASONIC BEAM PENETRATION DIAGRAM

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT
ULTRASONIC TEST RECORD

CONTRACT NO.______ BRIDGE NO.______ SCAN ORIG. ☐ R-1 2 3 4 5 ______

MATERIAL A36 ☐ A441 ☐ A517 ☐ OTHER______ THICKNESS______ TO ______

SPLICE SHOP ☐ FIELD ☐ LONGITUDINAL – WELD ☐ SCAN ☐ TRANSVERSE – WELD ☐ SCAN ☐

WEB ☐ FLANGE TOP ☐ BOTTOM ☐ SCAN TOP ☐ BOTTOM ☐ GIRDER______ SPAN______ SPLICE______ ANGLE______

NORTH ↑☐ ←☐ LAMINATION yes ☐ no ☐ EAST ↑☐ →☐

SOUTH ↓☐ →☐ LAMINATION yes ☐ no ☐ WEST ↓☐ ←☐

MANUAL ☐ SIMIAUTOMATIC ☐ AUTOMATIC ☐ OTHER ______ SINGLE "V" ☐ DOUBLE "V" ☐ 50-50 ☐ 1/3-2/3 ☐

REMARKS: ______

______ ULTRASONIC INSPECTOR ______ DATE ______

______ ULTRASONIC INSPECTOR ______

Form HMR T-6043 (Orig. 4/70)

Figure 7

ULTRASONIC TEST RECORD SHEET

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS RESEARCH DEPARTMENT

ULTRASONIC TEST SUMMARY

Contract No.	
Report No.	Date

Dist.	Co.	Rte.	P.M.	Material	Specifications
Fabricator		Instrument		Structure	

GIRDER IDENTIFICATION	ELEMENT	ACCEPTABLE	REJECTED	DISTANCE FROM O	DEFECT DEPTH	DEFECT LENGTH	LONGITUDINAL TRANSVERSE	REMARKS

JOB LOCATION	ULTRASONIC INSPECTOR SIGNATURE DATE
LOCATION OF ZERO N S E W T B	ULTRASONIC INSPECTOR SIGNATURE DATE

JOHN L. BEATON
MATERIALS AND RESEARCH ENGINEER

BY____________________________ DATE__________

Form HMR T-6044 (Orig. 4/70)

Figure 8

ULTRASONIC TEST SUMMARY SHEET

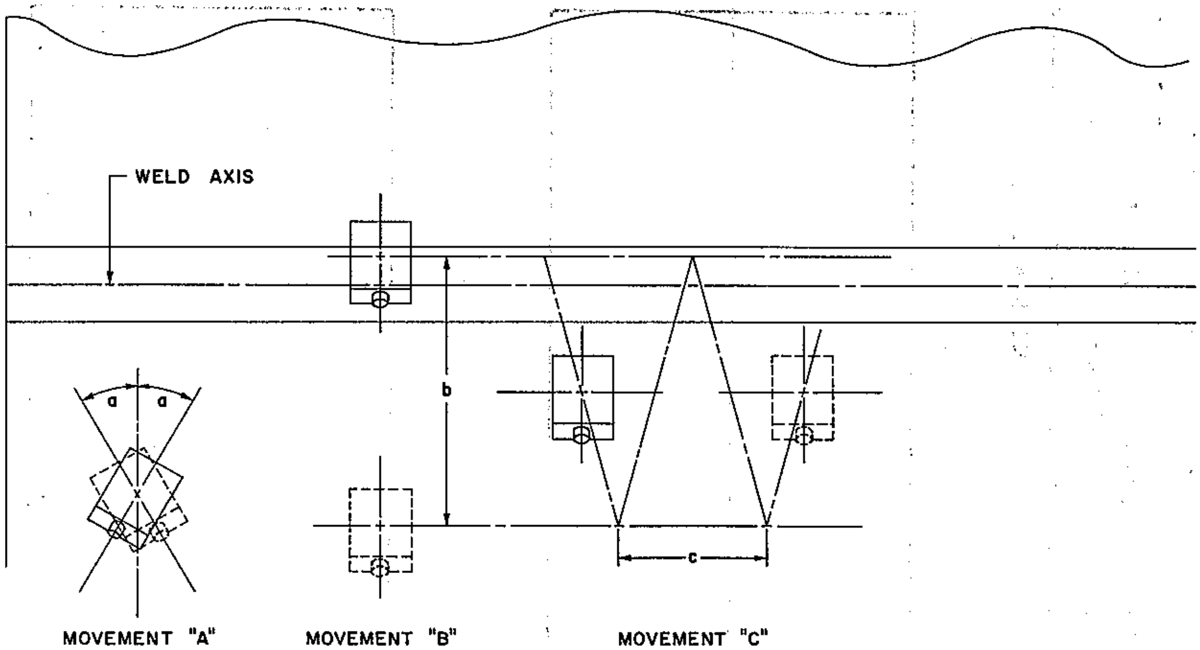


Figure 9
LONGITUDINAL SCANNING TRANSDUCER MOVEMENTS

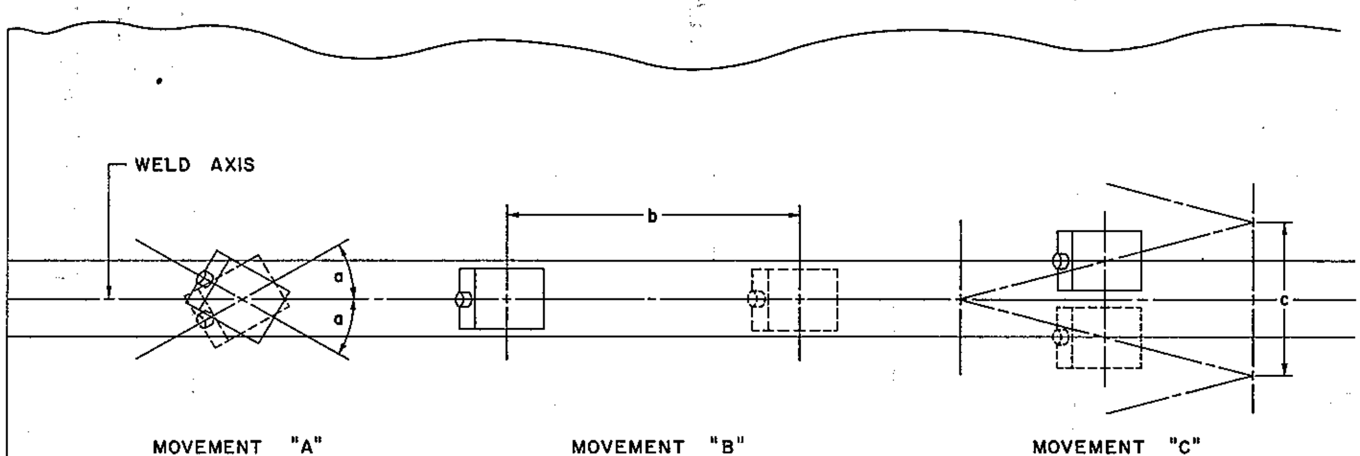


Figure 10
TRANSVERSE SCANNING TRANSDUCER MOVEMENTS

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

WELD DEFECT SKETCH SHEET

DRAWN BY ______________________ DATE __________

CONTRACT NO. __________ BRIDGE NO. __________

MATERIAL __________ THICKNESS __________ TO __________

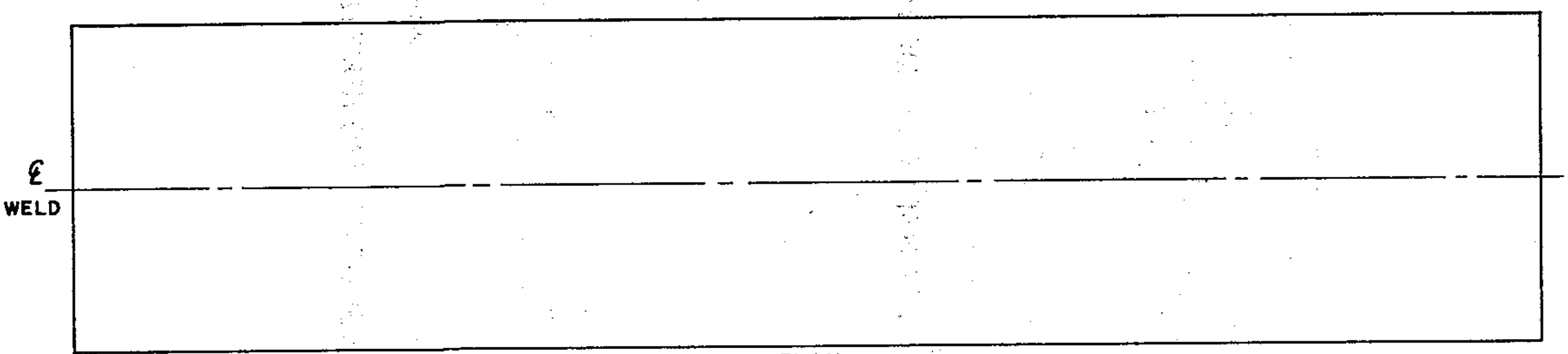
SPLICE ______ SHOP ☐ FIELD ☐

SPLICE ______ WEB ☐ FLANGE ______ TOP ☐ BOTTOM ☐

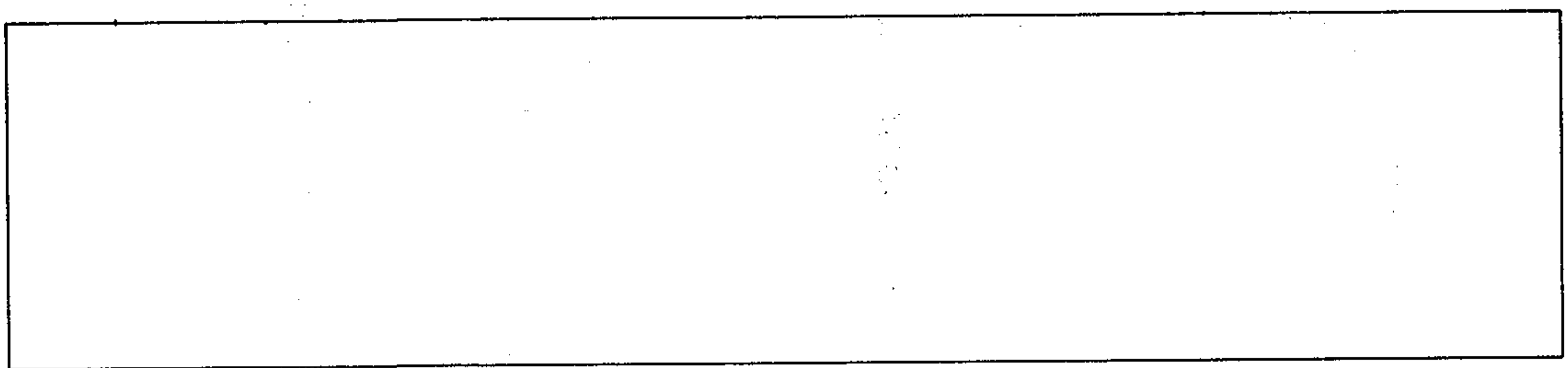
GIRDER __________ SPAN __________ SPLICE __________

NORTH

NO SCALE



PLAN



ELEVATION

Figure 11

WELD DEFECT SKETCH SHEET

HMR T-6047 (Orig.3/71)

repair no.

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT
ULTRASONIC TEST RECORD

CONTRACT NO. *03-052311* BRIDGE NO. *53-123* SCAN. ORIG. ☒ R-1 2 3 4 5 ____

MATERIAL A36 ☐ A441 ☐ A517 ☒ OTHER ____ THICKNESS *2¼* TO *2¼*

SPLICE SHOP ☐ FIELD ☒ LONGITUDINAL – WELD ☐ SCAN ☒ TRANSVERSE – WELD ☒ SCAN ☐

WEB ☐ FLANGE TOP ☒ BOTTOM ☐ SCAN TOP ☒ BOTTOM ☐ GIRDER *GA 21* SPAN *10* SPLICE *W-2* ANGLE *45°*

scanning direction — NORTH ↑☒ ←☐ LAMINATION yes ☐ no ☒ EAST ↑☐ →☐

4½" ← maximized location

extremities

0" *3¼"* *5½"* ℄ of weld *30"*

path

Clear

magnitude → *+2db V*

½" south of ℄ → *½ ℄S*

depth → *½"D* *①* ← flaw identification no.

length → *2¼"L*

SOUTH ↓☒ →☐ LAMINATION yes ☐ no ☒ WEST ↓☐ ←☐

4¼"

0" *3"* *5"* *30"*

+5db V

½ ℄S

½D

2"L *①*

Clear

MANUAL ☒ SIMIAUTOMATIC ☐ AUTOMATIC ☐ OTHER ____ SINGLE "V" ☐ DOUBLE "V" ☒ 50-50 ☒ 1/3-2/3 ☐

REMARKS: *SURFACE CONDITION IS SMOOTH AND ACCEPTABLE*

① REJECT

ULTRASONIC INSPECTOR *John V. Doe* DATE *3-2-71*

ULTRASONIC INSPECTOR *R. D. Jones*

Form HMR T-6043 (Orig. 4/70)

Figure 12

COMPLETED ULTRASONIC TEST RECORD SHEET (LONGITUDINAL SCAN)

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT
ULTRASONIC TEST RECORD

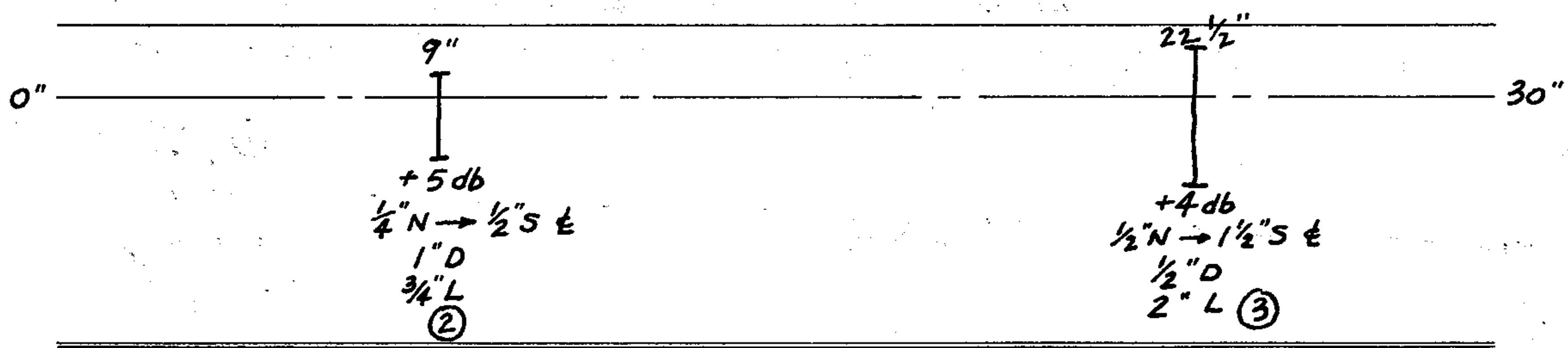
CONTRACT NO. 03-052311 BRIDGE NO. 53-123 SCAN ORIG. ☒ R-1 2 3 4 5 ____

MATERIAL A36 ☐ A441 ☐ A517 ☒ OTHER ____ THICKNESS 2 1/4 TO 2 1/4

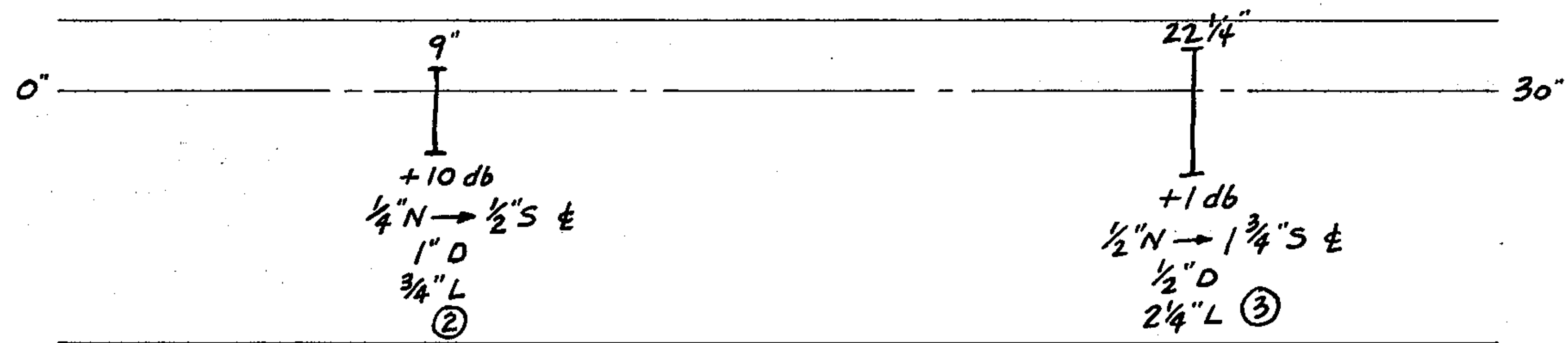
SPLICE SHOP ☐ FIELD ☒ LONGITUDINAL – WELD ☐ SCAN ☐ TRANSVERSE – WELD ☒ SCAN ☒

WEB ☐ FLANGE TOP ☒ BOTTOM ☐ SCAN TOP ☒ BOTTOM ☐ GIRDER GA 21 SPAN 10 SPLICE W-2 ANGLE 45°

NORTH ↑☐ ←☐ LAMINATION yes ☐ no ☐ EAST ↑☐ →☒



SOUTH ↓☐ →☐ LAMINATION yes ☐ no ☐ WEST ↓☐ ←☒



MANUAL ☒ SIMIAUTOMATIC ☐ AUTOMATIC ☐ OTHER ____ SINGLE "V" ☐ DOUBLE "V" ☒ 50-50 ☒ 1/3-2/3 ☐

REMARKS: 2 ACCEPT
3 REJECT

ULTRASONIC INSPECTOR John V. Doe DATE 3-2-71
ULTRASONIC INSPECTOR R. D. Jones

Form HMR T-6043 (Orig. 4/70)

Figure 13

COMPLETED ULTRASONIC TEST RECORD SHEET
(TRANSVERSE SCAN)

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

WELD DEFECT SKETCH SHEET

DRAWN BY John V. Doe DATE 3-2-71
CONTRACT NO. 03-052311 BRIDGE NO. 53-123
MATERIAL A-517 THICKNESS 2 1/4" TO 2 1/4"
SPLICE ____ SHOP ☒ FIELD ☐
SPLICE ____ WEB ☐ FLANGE ____ TOP ☒ BOTTOM ☐
GIRDER GA 21 SPAN 10 SPLICE W-2

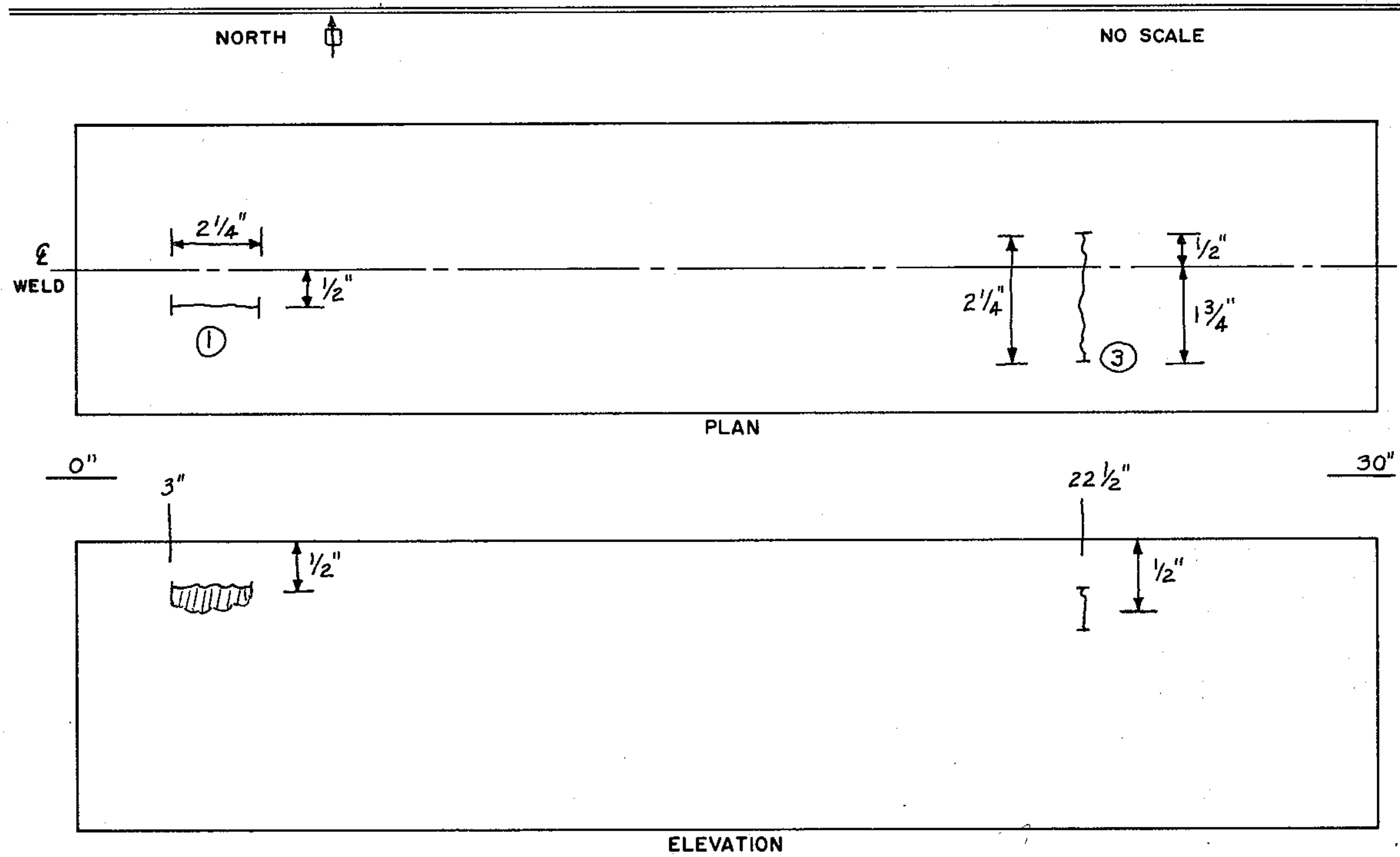


Figure 14

COMPLETED WELD DEFECT SKETCH SHEET

HMR T-6047 (Orig.3/71)

STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS RESEARCH DEPARTMENT
ULTRASONIC TEST SUMMARY

Contract No. 03-052311
Report No. 3 | Date 3-2-71

Dist.	Co.	Rte.	P.M.	Material	Specifications
				A517	CALIF 601

Fabricator: JONES STEEL | Instrument: BRANSON 301 | Structure: GREEN RIVER BRIDGE

GIRDER IDENTIFICATION	ELEMENT	ACCEPTABLE	REJECTED	DISTANCE FROM O	DEFECT DEPTH	DEFECT LENGTH	LONGITUDINAL TRANSVERSE	REMARKS
GA-21 W-2	T.F. 0-30		1	4½	½	2¼	L	+2 db
"	"	2					T	
"	"		3	22½	½	2¼	T	+1 db

JOB LOCATION: SAN FRANCISCO

LOCATION OF ZERO
N S E W T B

ULTRASONIC INSPECTOR SIGNATURE: John V. Doe — DATE 3-2-71

ULTRASONIC INSPECTOR SIGNATURE: R. D. Jones — DATE 3-2-71

JOHN L. BEATON
MATERIALS AND RESEARCH ENGINEER

BY R. A. Brown DATE 3-2-71

Form HMR T-6044 (Orig. 4/70)

Figure 15

COMPLETED ULTRASONIC TEST SUMMARY SHEET

APPENDIX "C"

CALIBRATION PROCEDURES

APPENDIX "C" - CALIBRATION PROCEDURES

Transducer positions for Calibration of the Ultrasonic Equipment with the Ultrasonic Reference Block or other approved Calibration Blocks are shown in Appendix B, Figure 5.

I. Longitudinal Mode

A. Distance Calibration

1. Place transducer in position "F" on the Ultrasonic Reference Block or position "G" on the Distance Calibration (DC) Block.

2. Adjust instrument to produce indications at 1", 2", 3", 4", etc. on the CRT screen.

B. Amplitude Calibration

1. Place transducer in position "F" on the Ultrasonic Reference Block or position "G" on the DC Block.

2. Adjust gain until maximized indication from the first back reflection is 90% - 100% screen height.

C. Resolution

1. Place transducer in position "E" on the Ultrasonic Reference Block.

2. Transducer and instrument combination shall clearly resolve all three distances represented in the slot configuration.

II. Shear Wave Mode (Transverse)

A. To determine or check the transducer sound emission index point.

1. Place transducer in position "D" on the Ultrasonic Reference Block.

2. Move transducer until signal from the radius is maximized.

3. The points on both sides of the transducer that are in line with the lines on the Ultrasonic Reference Block denote the precise transducer sound emission index point.

B. To determine or check the transducers sound path angle.

1. Place transducer in position "B" on the Ultrasonic Reference Block for angles 43° through 47° and 58° through 62°.

APPENDIX "C"

2. Place transducer in position "C" on the Ultrasonic Reference Block for angles 68° through 72°.

3. Move the transducer back and forth over the area of transducer angle graduations until the signal from the radius is maximized, then compare the sound emission index point on the transducer with the angle mark on the Ultrasonic Reference Block.

C. Distance Calibration Procedure.

1. Place transducer in position "D" on the Ultrasonic Reference Block (any angle).

2. Adjust the instrument to attain indications at 4 inches and 9 inches on the CRT screen. Care must be taken not to misconstrue the spurious transducer signal on the CRT screen in the vicinity of 8 1/2 inches sound travel for the 9 inch reflector which is the one desired.

3. Place transducer in position "H" on the Distance Calibration Block (any angle).

4. Adjust the instrument to attain indications at 1", 2", 3", 4", etc. on the CRT screen.

D. Amplitude or Sensitivity Calibration Procedure.

1. Place transducer in position "A" on the Ultrasonic Reference Block.

2. Adjust the maximized signal from the 1/16 inch diameter hole to attain a horizontal reference line (50% screen height) indication.

3. With an approved Ultrasonic Reference Block (Appendix B, Figure 1), the horizontal reference line height indication represents a standard: w/70° angle transducer, +0 db reflector, w/60° angle transducer, -1 db reflector, w/45° angle transducer, -3 db reflector.

4. With the transducer on the Sensitivity Calibration (SC) Block (Appendix B, Figure 3) position "I" for 70° angle, position "J" for 60° angle, or position "K" for 45° angle, adjust the maximized signal from the 1/16 inch diameter hole to attain a horizontal reference line height indication.

APPENDIX "C"

5. With an approved SC Block, the horizontal reference line height indication, with the transducer in the appropriate position and maximized, represents a standard -3 db reflector, in all three cases.

6. The appropriate decibel value shall be incorporated into the sensitivity calibration procedure to enable increasing the sensitivity to the scanning sensitivity (see Appendix B, Table I).

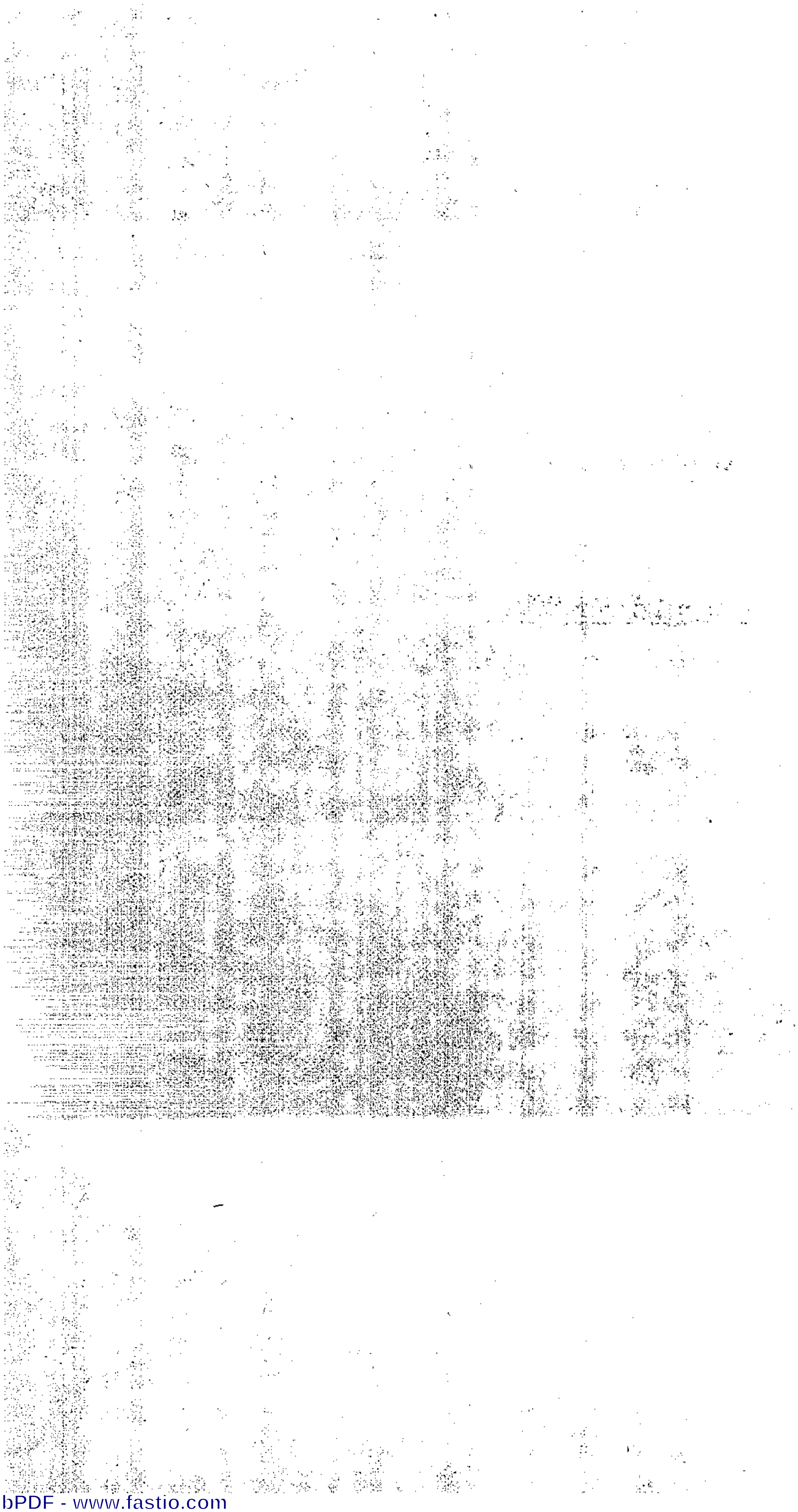
E. Resolution

1. Place transducer on the Resolution Block (Appendix B, Figure 4) at position "L" for 70° angle, position "M" for 60° angle or position ""N" for 45° angle.

2. The transducer and instrument shall clearly resolve the three test holes.

APPENDIX "D"

SCANNING PATTERNS



APPENDIX "D" - SCANNING PATTERNS

I. Scanning for longitudinal and transverse defects in a weldment (see Appendix B, Figures 9 and 10 respectively).

a. Scanning Movement "A" - the Rotation angle "a" = 10°.

b. Scanning Movement "B" - the scanning distance "b" shall be such that the full section of weld is inspected with both the slant and the "V" paths.

c. Scanning Movement "C" - the progression distance "c" shall be approximately one-half the transducer element width.

NOTE: Movements "A", "B", and "C" are combined into one scanning pattern.

II. Longitudinal scanning shall be conducted from both sides of the weld and on the same face where mechanically possible.

III. Transverse scanning shall be conducted in both directions and on the same face where mechanically possible.